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A Summary of Current Program, 4/1/62

and Preliminary Report of Progress

for 10/1/60 to 3/31/62

SOIL AND WATER CONSERVATION

RESEARCH DIVISION

of the

AGRICULTURAL RESEARCH SERVICE

UNITED STATES DEPARTMENT OF AGRICULTURE

This progress report of U.S.D.A. and cooperative research is primarily a tool for use of scientists and administrators in program coordination, development and evaluation; and for use of advisory committees in program review and development of recommendations for future research programs.

There is included under each problem area in the report a brief and very general statement on the nature of the research being conducted by the State Agricultural Experiment Stations and the professional manpower being devoted by the State stations to such research. Also included is a brief description of related work conducted by private organizations. No details on progress of State station or industry research are included except as such work is cooperative with U.S.D.A.

The summaries of progress on U.S.D.A. and cooperative research include some tentative results that have not been tested sufficiently to justify general release. Such findings, when adequately confirmed will be released promptly through established channels. Because of this, the report is not intended for publication and should not be referred to in literature citations. Copies are distributed only to members of Department staff, advisory committee members and others having a special interest in the development of public agricultural research programs.

This report also includes a list of publications reporting results of U.S.D.A. and cooperative research issued between October 1, 1960, and March 31, 1962. Current agricultural research findings are also published in the monthly U.S.D.A. publication, Agricultural Research. This progress report was compiled in the Soil and Water Conservation Research Division, Agricultural Research Service, U. S. Department of Agriculture, Beltsville, Maryland.

UNITED STATES DEPARTMENT OF AGRICULTURE
Washington, D. C.
July 1, 1962

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INTRODUCTION

The importance of soil and water conservation in the Nation's agriculture can hardly be overestimated. Without these natural resources there would be no agriculture - no food - no fibers--the Nation's very existence is dependent upon its soil and water resources. There is no way of measuring the worth of soil and water to the Nation in monetary value. These basic resources are truly indispensable--life on earth without them would be impossible. The impact of a sound program of conservation and management of the Nation's soil, water, air and forests dictates the need for an intensive national resources research program.

Many facets of soil and water research are carried out in the Soil and Water Conservation Research Division. For convenience and efficiency, the work is organized into three main categories: (1) Watershed Engineering Research; (2) Water Management Research; and (3) Soil Management Research. Altogether, 17 disciplines are involved with about 416 professional man-years. In presenting this progress report the work is grouped into 13 areas which correspond to the Division's Work Projects. An additional Area No. 14 deals with research relating to specific crops for reporting appropriate research to the different commodity Research and Marketing Advisory Committees.

Outstanding Accomplishments

1. Water harvest method developed.

Low-cost treatments for stabilizing and waterproofing soil surfaces have been developed at the U. S. Water Conservation Laboratory at Tempe, Arizona. These treatments are designed to increase precipitation runoff for stock-water and farmstead supplies. The treatments, consisting of an asphalt emulsion soil stabilizer and a chemical water repellent with or without plastic membranes, promise to produce water in 10-inch rainfall areas at a cost near 40 cents per 1,000 gallons. Costs are generally less with greater rainfall. Successful field tests have been made of water-storage bags consisting of butyl-coated nylon and vinyl-coated nylon and of cistern type storage units. Water collected and stored in these containers sustained no contamination or loss through a summer season.

The successful, low-cost treatment of the watershed collection area coupled with satisfactory storage facilities indicates that a successful solution to the problem of providing nominal quantities of stock and domestic water in remote areas can be achieved. The development is of particular importance to ranchers on many rangeland areas as it promises a dependable and economic source of livestock water that can be strategically located for efficient use and maintenance of their grazing lands.

Cooperative field testing is now underway with Salt River Project in Arizona, the Bureau of Indian Affairs and the Forest Service.

2. Development of a tillage guide for the Corn Belt.

Managing soil and water and providing the proper soil environment for the plant seedling are overshadowing weed control as the primary objectives of tillage. At Ames, Iowa, rapid progress is being made in preparing a "tillage guide" for corn for the major soil types in the western Corn Belt. The guide provides for the first time a means for the evaluation of soil characteristics as they exist and the changes brought about by tillage operations. The guide has divided a field planted to row crop into two zones. These zones are the soil immediately around the seed and seedling roots and the soil between the row. Measurements made with a microrelief meter, developed to evaluate surface roughness between the rows, show that reduced tillage systems, such as wheel-track planting and listing, have twice as great a potential water detention as conventional tillage. After field testing, this guide should provide the information needed for technicians to set up tillage methods for various cropping systems and soils that will give the maximum protection to our soil and water resources.

3. New concept of nutrient balance in fertilizer application developed.

Current trends for the use of higher rates of fertilizer in crop production now require new concepts of nutrient balance and absorption in relation to crop yields. At Beltsville, Maryland, the interrelations between the positive and negative charged substances (plant nutrients) absorbed from soils have been reexamined. Under conditions where high amounts of fertilizer are applied, substantial evidence has been accumulated that the main function of some nutrients is to supply positive charges. These positive-charged nutrients enable the plant to maintain the pH and organic acid content within a narrow range which is a prerequisite for good growth. With this newly acquired knowledge, it is anticipated that substantial changes in fertilizer mixtures available to the farmer can be expected in the future.

4. Method developed to determine short-term evapotranspiration rates from solar radiation.

Personnel at Fort Collins, Colorado, made an intensive study of the influence of incoming solar radiation on evapotranspiration. For these studies, evapotranspiration data were assembled from irrigation experiments that had been conducted in the 17 western states. Incoming solar radiation was estimated from climatic data in those areas where measured radiation data were not available.

Based on observation in humid areas whenever water and crop cover are ample, about 80 percent of the incoming radiation in an area is used to convert water from liquid to vapor in the course of evaporation and transpiration. The objective of the Fort Collins studies was to determine the fraction of the solar energy used in evapotranspiration as the crop season advanced in the drier half of the country.

As in humid areas, energy used in evapotranspiration increased as crop cover increased in the spring. Whenever water was limiting, however, less energy was used in evapotranspiration. Incoming energy that is not used in evapotranspiration usually heats the air and the soil. For this reason an irrigated area, adjacent to an unirrigated area, is cooler and therefore receives energy by advection from the unirrigated area. In the drier half of the country where advective energy from areas adjacent to the crop must be dissipated as well as the incoming solar energy, there was not a simple relationship between solar radiation and water use.

The Fort Collins study provides a picture of the energy to be dissipated in the western states during the crop season and the fraction that might be expected to be used for evapotranspiration. This permits short-term estimation of evapotranspiration during the growing season which results in a more reliable extension of irrigation information from one area to another.

5. Subsoil acidity influences the rooting depth of crops.

Shallow root development causes plants growing on many soils to suffer from drouth damage when the subsoil contains adequate moisture. Subsoil acidity is thought to be one of the main causes of this limited root development. In studies conducted at Auburn, Alabama, it was found that soybean roots develop and absorb moisture from subsoils with extremely low pH values and high levels of exchangeable aluminum, provided the surface soil received fertilizer and lime. Cotton roots were considerably more sensitive than soybeans to subsoil acidity. Sudangrass roots were even less tolerant, exhibiting the coral-like appearance which is associated with aluminum toxicity. From these data it appears that soybeans will develop normal root systems on soils with acid subsoils, but cotton and sudangrass will have shallow root systems unless a source of calcium is supplied to the subsoil. With this information it should be possible to develop liming schemes that will assure maximum root development of most crops growing on acid soils.

6. New rainfall patterns discovered for rangeland watersheds in the Northwest.

The raingage network of approximately one recording raingage per square mile on the 93.5 square-mile Reynolds Creek watershed southwest of Boise, Idaho, has provided startling new information on rainfall patterns on rangeland watersheds in that area. Records from the few previously existing gages in the region indicate the 1-hour, 100-year frequency storm on the Reynolds Creek area as 0.50 to 1.00 inch. The network has shown three storms on the watershed in the last two years that exceeded this and 10 storms which exceeded the 30-minute 100-year frequency of 0.50 to 0.75 inch. Intensities reached values up to 7.0 inches per hour for short bursts of time up to 10-20 minutes. Storm cells are commonly 2-5 square miles in area. Information on rainfall characteristics, such as cited here, is of great value to the design engineer as an index to the probable occurrence of flood events in small watersheds which are, as yet, but poorly documented in the region. The findings will be used by the Soil Conservation Service, Bureau of Reclamation, Corps of Engineers, Irrigation Districts, and Highway Departments.

7. Wind erosion prediction equation developed.

At Manhattan, Kansas, an important milestone in research on wind erosion has been reached with completion of a simplified wind erosion equation which, when applied to any field anywhere, will tell whether or not the field is sufficiently protected from wind erosion. Moreover, the equation can be used as a tool to estimate what field conditions a farmer should establish to reduce wind erosion to an insignificant amount.

The equation's usefulness lies in its simplicity. First, the condition of each of the five major factors that influence wind erosion is determined for the field by specified procedures. These factors are: Percent soil fractions larger than 0.84 millimeters in diameter as determined by standard dry sieving; local climatic factor based on average wind velocity and moisture of soil surface; soil surface roughness based on surface clods and ridges; equivalent field width along prevailing wind direction; and equivalent quantity and orientation of vegetation. With numerical values of these factors the potential amount of wind erosion of the field is read from accompanying charts and tables.

The equation is a potent new tool that is expected to aid technicians and agricultural leaders in field application of soil conservation principles and in education work. The area of application is primarily the vast dryland farming areas of the High Plains. Other areas of application are the dryland and irrigation farms of the west and some intensively cropped sandy soils of the humid region.

8. "Sick legumes" due to inoculation failure corrected by proper management.

At Pullman, Washington, results indicate that poor growth of alfalfa on certain soils in eastern Washington is associated with ineffective inoculation. "Sick legumes" were largely eliminated and effective nodulation obtained by application of lime, phosphorus, and sulfur. Thoroughly mixing the top four feet of soil and applying lime, phosphorus and sulfur improved the growth of first-year alfalfa as compared to the treatment receiving only fertilizer. Additional work on the inoculation, nutrition and environmental facets of the problem will be required before final recommendations can be made to farmers.

9. Precise measurement of silt density.

An instrument that gives a precise measurement of the density of silt in a reservoir has been perfected at the Sedimentation Laboratory, Oxford, Mississippi. This has been previously reported as an instrument that was under development -- it is now a fully operative piece of equipment ready for wide-spread field use. Measurements of depths or thicknesses of silt are relatively simple with traditional methods, but the necessary measurements of densities, or weights per cubic foot, have long been a laborious problem, sometimes almost impossible of solution. Measurements of silt density are necessary both to forecast the useful life of reservoir storage and to relate the silting problem back to the source of the silt in the watershed. The new instrument, assembled from an assortment of standard component parts plus some new ideas of research personnel, operates on the principle of radiation from a radium isotope. It will be especially useful in making precise and rapid assessments of the silting problems of small reservoirs such as are constructed under the authority of Public Law 566.

10. Sod-based rotations essential for erosion control on Piedmont farms.

Runoff and soil loss data at Watkinsville, Georgia, show there is little hazard from erosion on sloping land, even under very severe rainfall conditions, when row crops follow sod crops on the land. Rainfall in 1961 was 33 percent above normal and the rainfall erosion index was 200 percent of the 22-year average. Actual rainfall runoff and soil losses on contour farmed Cecil sandy loam soil of 7 percent slope 70 feet long were:

Cropping treatment	Rainfall inches	Runoff inches	Soil loss Tons/acre
Cotton continuously	63.7	21.0	28.1
4-year rotation of fescue, fescue, corn, and cotton	62.1	7.2	4.2
3-year rotation of fescue, fescue, and corn	62.1	2.5	0.6

Soil losses for the 3-year rotation with corn one year in three were 2 percent and for the 4-year rotation with two years of row crops in four were 15 percent of that with cotton grown continuously. With the 3-year rotation only 4 percent of the annual rainfall left the field as surface runoff, but with continuously grown cotton 33 percent of the rainfall left the fields loaded with soil to muddy the streams of the area. Yields of the row crops were much higher in the rotations than when grown continuously.

These findings indicate sod-based rotations are essential for row crop production on the sloping Piedmont soils that extend from Maryland through North Carolina, South Carolina, Georgia and into Alabama.

11. Retarding reservoirs recharge ground water.

Instrumentation has been partially established on the Lowrey Draw watershed in the vicinity of Sonora, Texas, to provide information on the effects of floodwater retarding reservoirs upon ground water recharge in the Edwards Plateau area. Data are available from only a few runoff events; but, in these cases, there has been a marked increase in the level of some ground water observation wells associated with impoundments in the surface reservoirs. Much more data will be necessary to define relationships between surface and ground waters in this cavernous limestone region. It is anticipated, however, that the studies will provide information on the sources of ground water in the area and guidelines for ground water recharge in limestone regions by means of watershed protection measures.

12. Gaseous losses of nitrogen measured in the field.

Until recently it has been assumed that nitrogen in the soil was either taken up by the plants or lost primarily by leaching. Recent laboratory studies have suggested that significant losses as gaseous nitrogen may also occur when most sources of nitrogenous fertilizers are applied to soils. Accordingly, studies are conducted at Thorsby, Alabama, to evaluate the actual losses under field conditions. Both cropped and uncropped plots were used and two sources of nitrogen, namely, ammonium sulfate and sodium nitrate, applied at the rate of 200 pounds nitrogen per acre. Under these experimental conditions 20 to 30 pounds of the added nitrogen was not accounted for and assumed

to have been lost in the gaseous form. The losses of nitrogen from the cropped soil were less than from the uncropped soil, probably because of the rapid removal by the crop of the nitrogen which was most likely to be converted into gaseous forms. Very little difference was found in the gaseous nitrogen losses from the two sources of nitrogen, or the time of application. The mechanism of these observed losses is not fully understood.

13. Relative leaf turgidity for irrigation of cotton.

The rapid rise in the use of supplemental irrigation in recent years has increased the need for a criterion for determining when water should be applied to plants. At Weslaco, Texas, the use of moisture stress within the plant as an irrigation criteria for cotton indicates that the method can very readily be used for determining when to irrigate. Excellent control of timing of irrigation applications was obtained, based on relative turgidity measurements made on cotton leaves. The time of wilting of the cotton plant was strongly influenced by the amount of moisture in the first foot of soil. However, for any given soil moisture condition, the time of wilting was also associated with the temperature and vapor pressure around the plant. Although this method offers considerable possibilities in determining when to irrigate, additional studies will be required before the principal can be applied to farmers' fields.

14. Improved device for irrigation water measurement.

Accurate irrigation water measurements and simple, economical devices for making the measurements are required for improving irrigation water use efficiency. Two developments at Fort Collins, Colorado, have made significant contributions to these two phases of irrigation water measurement. One is a simplified method for determining accurate flow measurement for flat channels where drop structures are not feasible. The other shows how the water-measuring device can be installed at reduced cost without adversely affecting accuracy of the measurements. Both developments are for the standard Parshall measuring flume, a device generally made of sheet metal, wood or concrete which replaces a short section of a water conveyance channel.

Accurate flow measurements can be made with a Parshall flume without a drop at the outlet end if the depth of water is measured at specified points in both the outlet and inlet sections. The ratio of these two depths is known as a submergence. The amount of submergence determines a correction factor that is applied to the depth-flow relation without submergence for the correct flow measurement with submergence. A simplified procedure was developed for making these determinations.

Related investigations have also shown that the convergence angles of Parshall flumes can be changed from the standard of 11°19' to 7°25' with only a 1-percent variation in the head-discharge relationship. Results indicate that the angle of convergence can be altered within limits indicated to accommodate a particular canal or design without materially changing the rating curve. Considerable savings in future construction costs of measuring sections in canals should be possible as a result of the findings.

These findings are expected to have use by both irrigation districts and individual farmers throughout the irrigation farming areas of the Western States.

15. Irrigation water supply prediction.

In the western mountains, the most important source of irrigation water is from the melting snow pack. An electronic analog has been developed at Moscow, Idaho, for calculating estimates of streamflow from snowmelt on source areas of the Pacific Northwest. The following are involved in the computations: Snow storage and melting related to climatic, topographic, and vegetational character; losses from evapotranspiration varying with climatic factors; rainfall contribution; soil moisture storage; ground water storage and discharge; and observed streamflow. The analog is being used primarily as a research tool for the refinement of forecasting techniques at the present time. It greatly speeds up calculation processes, however, and has great potential for handling large volumes of snow survey data in connection with water supply forecasts.

AREA 1 SEDIMENTATION PROCESSES IN RELATION TO WATERSHED DEVELOPMENT AND PROTECTION

Problem. Sediment is the largest single pollutant of the nation's streams. It damages fish and wildlife, reduces reservoir storage capacity, clogs highway and drainage ditches, fills stream channels causing increased flooding, and otherwise distract from the inherent values of riparian lands. Sediment adds to the costly cleanup following floods and must be removed from domestic and industrial water supplies. In many parts of the country abatement of sediment damages is one of the primary justifications for watershed protection and development programs. Sediment is the product of erosion and the ability of the stream channel system to transport the eroded material. Most of the sediment burden is derived from erosion on agricultural lands and the stream channel systems in agricultural watersheds. The processes of sedimentation are complex, and an understanding of the controlling factors is essential for the development of practices and programs for solution of sediment problems. The relationship between sediment load, streamflow, land use, and watershed characteristics needs to be clarified through research. Improved criteria are also needed for computing the bedload movement of sand, gravel, and other coarse debris; for understanding the processes of reservoir sedimentation; and for the design of means and measures for stream channel stabilization.

USDA PROGRAM

The Department has a continuing long-term program involving hydraulic engineers, soil scientists, soil physicists, geologists, physical chemists, agronomists, and range scientists in both basic and applied studies of sedimentation processes for the purpose of developing and proving new information useful in the solution of various sediment and stream channel problems. The studies are in progress in the 13 states of Arizona, Georgia, Idaho, Illinois, Iowa, Kansas, Mississippi, Missouri, New Mexico, Nebraska, Oklahoma, South Dakota, and Texas where they are cooperative with the State Agricultural Experiment Stations. Other cooperators in these studies include the Illinois State Water Survey, the University of Mississippi, the Massachusetts Institute of Technology, and the California Institute of Technology.

The Federal scientific effort devoted to research in the area totals 24.1 professional man-years. Of this number, 12.1 man-years are devoted to studies of sediment sources and yields from agricultural watersheds; 2.7 to rates and processes of reservoir silting; 4.5 to mechanics of sediment entrainment, transportation and deposition; 4.2 to stream channel morphology and means and measures for stabilization; and 0.6 to structural developments for sediment control.

RELATED PROGRAMS OF STATE EXPERIMENT STATIONS AND INDUSTRY

State Experiment Stations in 1961 reported a total of 3.6 professional man-years divided among the subheadings as follows: Sediment sources and yields from agricultural watersheds, 0.2; mechanics of sediment entrainment, transportation and deposition, 2.6; stream channel morphology and means and measures for stabilization, 0.3; and structural developments for sediment control, 0.5. The bulk of the studies in this area involve the mechanics of flow in alluvial channels, particularly as it is affected by bed material and resistance to flow. Research is being conducted to develop structural systems which will control sediment movement within a feasible farm management plan. More effective means of measuring sediment and new sediment sampling equipment are being investigated.

Industrial organizations are not engaged in sedimentation research, but other branches of the Federal government and a few State agencies do have activities in this area to varying degrees. These include the Geological Survey and the Bureau of Reclamation in the Department of the Interior; the Corps of Engineers in the Department of the Army; and the Tennessee Valley Authority. The Forest Service in the Department of Agriculture conducts some research on sedimentation processes related to forest lands and establishes sediment control measures on forest lands. The Soil Conservation Service is concerned with the application and evaluation of various measures and practices for sediment control in connection with watershed protection activities and other operations programs. The Agricultural Research Service and the above agencies have representation on the Sedimentation Subcommittee of the Federal Inter-Agency Committee on Water Resources. This Subcommittee is concerned with the dissemination of information on various aspects of sedimentation among its members and sponsors a number of important joint efforts among member agencies.

REPORT OF PROGRESS FOR USDA AND COOPERATIVE PROGRAMS

A. Sediment sources and yields from agricultural watersheds

Conventional measurements of sediment yield from watersheds provides an estimate of a sediment load passing a point but no information on the origin or distances traveled by the individual particles. A procedure was developed at the Sedimentation Laboratory, Oxford, Mississippi, for tagging individual sand grains with Scandium 46 by heat treatment. The sand particles so treated were placed in a corn field at the North Mississippi Branch Agricultural Experiment Station and their movement traced over a 3-week period during which several runoff producing rains occurred. Monitoring indicated that one particle moved as far as 50 feet and that no particles remained at the site of seeding. These and other tests suggest that radio-isotopes may be useful tools in studying the rates of sediment movement in

watersheds and lead to a better basis for relating sediment yields to erosion sources upstream.

At the Sedimentation Laboratory, Oxford, Mississippi, improved methods were devised for constructing sediment rating and flow duration curves, and for using these curves to compute long-term sediment yields. Employing these techniques, it was found that long-term sediment yields varied from 0.11 to 6.4 tons per acre annually for 31 watersheds less than 100 square miles in area in Iowa, Ohio, Wisconsin, Pennsylvania and Mississippi. The lower sediment yield rates were from watersheds having high percentages of grassland cover and low runoff rates, whereas the higher yields were from watersheds having high basic erodibility and high storm runoff.

Measurements in northern Mississippi continue to show that most of the annual sediment yield from 1- to 4-acre watersheds occurs during a few storms each year that produce only a small percentage of the total annual runoff. High sediment yields from cultivated fields in this area are closely related to high intensity rains during the planting and early growing season when there is little or no vegetative cover and the topsoil is in an unstable condition.

At Cartersville, Georgia, studies aimed toward developing corrective measures to reduce sediment contributed from highway cuts and fills disclosed Crownvetch, nursed the first year by a grown-in-place mulch of Abruzzi rye, to be an uncommonly promising plant for stabilizing cut banks. Mulching was beneficial for establishing most plant species on slopes of 2 to 1, and was a necessity for steeper slopes. In general, clean crop residue mulches were best of 15 different mulching materials tested.

Of 25 factors tested, the peak discharge plus volume of runoff per storm event was found to be the best indicator of sediment yield from two 400-acre watersheds near Hastings, Nebraska. Sediment yields were also shown to be distinctly related to rainfall energy but the effect of the energy factor was not as significant on these watersheds having mixed land uses and complex slopes as on fraction-acre size plots.

Headward cutting of overfalls in the Medicine Creek watershed in western Nebraska advanced further during the dry 1952-58 period than during extremely wet 1951, but the channels produced only one-third the sediment yield in the 7-year dry period as in the one wet year. Surveys indicate that material eroded from the channel head cuts was deposited a short distance downstream in the dry years. During a wet year, such material is apparently carried out of the watersheds. This would indicate that, during a series of dry years, some channel systems are charged with erosional material that awaits a wet year to be delivered from the watershed.

At Riesel, Texas, sediment yields from a 132-acre conservation-treated watershed were found to be much less than from a 172-acre watershed with no special conservation practices. For a single, severely erosive storm, the sediment yields were 0.76 and 4.28 tons per acre, respectively, a ratio of 1 to 4.84 in favor of the conservation treatment. Another severe storm produced sediment yields in the ratio 1 to 5.63. Highly significant correlations were found between sediment concentration and rates of runoff during the recession flows for several of the watersheds during individual storms. By introducing factors of season, storm energy, and storm characteristics, reliable methods for predicting sediment yield from small watersheds in the Texas Blacklands may be developed.

Sediment accumulations are being measured in stock ponds (tanks) on the Walnut Gulch Experimental Watershed at Tombstone, Arizona, and the mean annual yield of sediment from their watersheds compared with soil and vegetation conditions. Results so far indicate that density of grass cover is closely related to the yield of sediments from these small watersheds. In four stock ponds ranging in age from 5 to 22 years, surveys show that average annual sediment from their drainage areas varies inversely as the logarithm of the basal area of grasses. The average annual sediment yield from predominantly brush-covered areas has been from two to three times that from the grass-covered ones, but no such regular relationship with brush cover is apparent.

B. Rates and processes of reservoir silting

Further field and laboratory testing and calibration of the gamma probe for determining the densities of reservoir sediments in situ were carried out at the Sedimentation Laboratory, Oxford, Mississippi. This instrument, which measures the density of sediments as a linear (log) function of the attenuation of gamma rays from radium-226, gives excellent precision and is now ready for general use on reservoirs of moderate depth. The instrument provides an important new basis for expressing volumes of reservoir sediment in terms of dry weight and thus greatly enhances their utility as indices of sediment yield from the contributing drainage areas.

The extent of variations in the volume-weight of reservoir sediment is indicated by measurements on Sabetha Lake in Kansas where the dry weights were found to range from 30 to 87 pounds per cubic foot. Volume-weights decreased downstream from the head of the lake to the dam, and varied inversely with the clay content of the sediment. They increased with depth within thick deposits of sediment. The studies on this lake emphasize the necessity of making quite detailed volume-weight measurements when the deposited sediment is to be expressed as sediment yield per unit of watershed area.

C. Mechanics of sediment entrainment, transportation and deposition

Means of measuring or computing accurately the total sediment transported by a stream at a particular stage continues to be a problem in both research and project development. Because of physical limitations, conventional sediment samplers cannot sample closer to the stream bed than about 0.3 foot on a smooth stream bed, thus they give highly uncertain results when dunes are present on the channel bottom. Studies of the relationship between sampler nozzle orientation and dune faces, utilizing the 100-foot flume at the Sedimentation Laboratory, Oxford, Mississippi, have shown concentration variances of several hundred percent when dune action was occurring. The significance of this when applied to sampling under field conditions has not been established but the implication is that even under the best conditions the concentrations of bed material in the sample could be in error.

In a series of model tests in the 100-foot flume at the Sedimentation Laboratory, Oxford, Mississippi, it was found that sand size particles were thrown into suspension when passing through a Parshall flume and that a flume of this type could be used as a total load measurement structure for sands and smaller particle sizes. Plans are now in progress to install such a station on Laboratory Creek for further studies of bed material movement in relation to stream discharge. Improvement in equations for estimating sediment transport will result in more reliable estimates of total sediment yield and aid in the design and maintenance of stream channel improvement measures.

Contract research on the flow of water over sand beds in laboratory channels at California Institute of Technology, Pasadena, California, determined that the length of stationary water waves and associated antidunes of the sand bed is equal to $2\pi V^2/g$, where V is the mean velocity of the water and g is the acceleration due to gravity. Measured values of wave length and water speed in the Little Colorado River near Cameron, Arizona; Virgin River near St. George, Utah; Gravel Pit Creek near Byhalia, Mississippi; and at five locations in the Pigeon Roost Creek watershed near Holly Springs, Mississippi, were in good agreement with the laboratory observations. These waves break when their height reaches one-seventh the wave length. Stationary waves that did not break had little effect on the sediment transport or the friction factor of the stream. In the laboratory, wave form, frequency of breaking, and violence at breaking differed for the two sizes of sand used. For the 0.55 mm. sand the dominant wave form was three-dimensional (rooster tail type) and caused little change in sediment transport or hydraulic friction at the time of breaking. With the 0.23 mm. sand the waves were dominantly of the two-dimensional type; they formed more frequently, broke more violently, and caused relatively large increases in sediment transport and effective roughness of the channel.

D. Stream channel morphology and means and measures for stabilization

Contract and cooperative research with the Massachusetts Institute of Technology, Cambridge, Massachusetts, has shown that laboratory models can be used to determine the detailed distributions of relative values expressing the intensity of attack of a stream against its boundaries. In this study, the distributions of boundary shear stresses were expressed in terms of the mean value for the approach flow. The variables were depth of flow, boundary roughness, and asymmetry of velocity distribution in the approach flow. The latter variable was used to simulate an upstream reverse curve, and an upstream compound curve, all having a 60^{o} bend with radius of outside bank approximately equal to twice the stream width. The maximum shear stress along the outside bank of the bend was about twice the mean for the approach flow, being a little greater for the compound curve and for the rough boundary, and a little less for the reverse curve. The attack on the inside bank of the bend was severe as the water entered the bend, a situation which sometimes occurs in natural channels. The accumulation of such knowledge in the field is a very slow and cumbersome process and the prospect of being able to approach the problem through model studies is very encouraging.

Water temperature has a significant effect upon the ability of cohesive materials to withstand the hydraulic action of flowing water, as determined by intensive experiments in a small, specially designed flume at the Sedimentation Laboratory, Oxford, Mississippi. The same experiments are demonstrating that the percent and type of clay minerals present in the soil and the volume weight of the soil are also significant factors in establishing its cohesiveness and resistance to dynamic fluid action.

Dynamic changes in channel profiles were found to occur following the construction of a gully-control structure. Studies of changes in channels above and below gully-control structures in Wisconsin revealed the severity and variability of channel cutting and filling caused by the installation of such structures. Preliminary analysis of data from the field survey of numerous gully-control structures shows that, in general, downstream channel degradation followed soon after structure installation. Gradually, this cutting rate decreased and the channel grade became relatively stable for awhile. Then as the basin upstream from the structure filled with sediment and its trap-efficiency decreased, more material was carried through the structure, and the downstream channels tended to fill, sometimes seriously reducing the hydraulic capacity of the structure. Knowledge of causes of such channel changes will make it possible to determine the height and spacing of structures as well as the depth of cut-off walls and footers, all necessary for economic and adequate designs.

A noted correlation has been found between bank sloughing or erosion and the clay content of bank materials along Fisheating Creek in Florida. Reaches of this dug channel in highly uniform sands sloughed badly, whereas those reaches with 2 to 5 percent clay in the bank material presented little erosion problems.

At Chickasha, Oklahoma, a cursory study of the geology and morphology indicate three distinct cycles of erosion and deposition in the development of the Washita River channel and flood plain area. The Basin may still be in the third cycle or possibly just beginning a fourth. The main river channel presents many distinct features along its meandering length of some 650 miles. The upper portion is wide, shallow, and sandy, where there is considerable lateral shifting of the channel. This is followed in succession by a stable, tree lined reach; a reach with steep, high banks and a narrow channel; a reach with serious bank erosion, channel deterioration and widening; and a highly stable reach due to the presence of considerable bed rock in the channel. The studies in the Washita River Basin are aimed primarily toward an understanding of channel stability, flood flows, and water and sediment yields along the main stem of the Washita River in relation to the application of watershed protection measures in upstream tributaries. Knowledge of the geologic trends is essential to a proper evaluation of the influences of man's activities upon the channel conditions.

Cross sections have been prepared from surveys along a 9-mile reach of the main stem of the Walnut Gulch Experimental Watershed at Tombstone, Arizona, to study channel aggradation, degradation and alignment changes relating to major runoff events and any long-period cycling of the flow regime. Plans are proceeding for similar studies on the Alamogordo Creek Experimental Watershed near Santa Rosa, New Mexico. Studies at this location involve problems of head cutting and rapid channel development through a presently well-grassed, deep, valley alluvium on a major branch of the watershed channel system.

PUBLICATIONS REPORTING RESULTS OF USDA AND COOPERATIVE RESEARCH

Sediment Sources and Yields from Agricultural Watersheds

Diseker, E. G., and Richardson, E. C. 1961. Measurement and control of erosion from highway slopes. Tenth Ann. Ga. Highway Conf. Proc., 12 pp.

Diseker, E. G., and Richardson, E. C. 1961. Roadside sediment production and control. Amer. Soc. Agr. Engin. Trans., 4, pp. 62, 63, 64 and 68.

Diseker, E. G., and Richardson, E. C. 1961. Highway erosion research studies. Twentieth Short Course on Roadside Development Proc., pp. 65-75.

Doty, C. W., and Dendy, F. E. 1961. Improved management reduces soil and water losses. Assoc. South. Agr. Workers, Inc. Proc. 58th Ann. Conv., p. 42.

Hendrickson, B. H. 1961. Conference on roadside erosion control. Jour. Soil and Water Conserv., 16, p. 289.

Richardson, E. C., and Diseker, E. G. 1961. Roadside mulches. Crops & Soils, 13, p. 16.

Richardson, E. C., and Diseker, E. G. 1961. Control of roadbank erosion in the Southern Piedmont. Agron. Jour., 53, pp. 292-294.

Rates and Processes of Reservoir Silting

Heinemann, H. G. 1961. Sediment distribution in small floodwater-retarding reservoirs in the Missouri Basin Loess Hills. U. S. Dept. Agr. ARS 41-44, 37 pp.

Mechanics of Sediment Entrainment, Transportation and Deposition

Kennedy, J. F. 1961. Stationary waves and antidunes in alluvial channels. Cal. Inst. Technol., W. M. Keck Lab. Rpt. KH-R-2, 146 pp.

Kennedy, J. F. 1961. Further laboratory studies of the roughness and suspended load of alluvial streams. Cal. Inst. Technol., W. M. Keck Lab. Rpt. KH-R-3, 36 pp.

Stream Channel Morphology and Means and Measures for Stabilization

Ippen, A. T., Drinker, P. A., Jobin, W. R., and Noutsopoulos, G. K. 1960. The distribution of boundary shear stresses in curved trapezoidal channels. Mass. Inst. Technol. Tech. Rpt. 43, 83 pp.

Ippen, A. T., Drinker, P. A., Jobin, W. R., and Noutsopoulos, G. K. 1960. Basic data supplement to Technical Report No. 43: The distribution of boundary shear stresses in curved trapezoidal channels. Mass. Inst. Technol. Tech. Rpt. 43-S, 44 pp.

AREA 2 HYDROLOGY AND WATER RESOURCES RELATED TO AGRICULTURAL WATERSHEDS

Problem. The Department's Conservation Needs Inventory indicates nearly 12,000 watersheds in the country of a size suitable for projects under the Watershed Protection and Flood Prevention Act, the Small Reclamation Projects Act, and similar programs. About 8,300 of these watersheds need project action for such purposes as flood prevention, development of water supplies, development of public recreation and fish and wildlife areas, irrigation, drainage, and various related group enterprises. Efficient planning and execution of programs for protection and development of upstream watersheds require an understanding for the basic factors governing the hydrology of agricultural watersheds and their associated aquifers. Research-derived procedures for estimating floodflows, water yields, hydrograph shapes, base flow, and ground water accretions in relation to the use and treatment of watershed lands in the various geo-climatic regions of the country are an urgent need. Research on relations between improvement works in upstream tributaries and floodflows and water yields downstream along the principal tributaries and the main stems of major rivers is also a conspicuous need. This research provides an insight into the operation of the hydrologic cycle in agricultural watersheds. From it are derived prediction equations and criteria for the more efficient design of watershed programs and utilization of water resources.

USDA PROGRAM

The Department has a continuing long-term program involving hydrologists, geologists, meteorologists, soil scientists, range scientists, and statisticians in both basic and applied research on the hydrology of agricultural watersheds. The studies are aimed primarily toward providing information useful in connection with the protection and development of resources in upstream watersheds. The work is in progress in the 17 states of Arizona, California, Florida, Idaho, Maryland, Mississippi, Missouri, Nebraska, New Mexico, Ohio, Oklahoma, South Dakota, Texas, Vermont, Virginia, West Virginia, and Wisconsin. All work is cooperative with the respective State Agricultural Experiment Stations. Other cooperators in these studies include State of California, Department of Water Resources; Santa Barbara County Water Agency; Central and Southern Florida Flood Control District; Geology Department, Oklahoma State University; Vermont State Water Conservation Board; Potomac Valley Soil Conservation District; Wisconsin Valley Improvement Association, and a large number of individual farmers and ranchers throughout the United States.

The Federal scientific effort directed to this area of research totals 46.1 professional man-years. Of this number, 7.7 are devoted to studies of precipitation patterns; 4.1 to soil moisture accretion and depletion; 3.6 to ground water accretion, movement and basin recharge; 6.6 to aquifer-streamflow relationships; 10.3 to water yield and water supply and quality; 12.0 to floodflows and storm runoff; and 1.8 to criteria for watershed protection.

RELATED PROGRAMS OF STATE EXPERIMENT STATIONS AND INDUSTRY

State Experiment Stations in 1961 reported a total of 14.9 professional man-years divided among subheadings as follows: Precipitation patterns, 0.5; moisture accretion and depletion, 2.6; ground water accretion, movement and basin recharge, 2.9; aquifer-streamflow relationships, 0.6; water yield and water supply and quality, 5.9; floodflows and storm runoff, 2.0; criteria for watershed protection, 0.3; and water use by phreatophytes, 0.1. Research is being conducted on the part played by algae and molds on moisture exchange; recharge of ground water basins with particular reference to development of effective means of removing sediment; improvement in forecasting both annual and seasonal water supply; development of water resources; runoff characteristics of agricultural areas; and determination of the factors of slope, soil and management practices which conserve moisture and reduce erosion.

Industry and other organizations. No records of research by private industry in the field of hydrology in 1961 are available. Data on streamflow and ground water inventories were obtained by the U. S. Geological Survey, usually in cooperation with States on a matching funds basis. The Corps of Engineers, Bureau of Reclamation and Tennessee Valley Authority continued streamflow measurements and water resource investigations incident to their assigned responsibilities. The U. S. Weather Bureau continued to obtain information on precipitation and climatic factors. The aforementioned are primarily data-gathering rather than research activities and are principally applicable in connection with specific project developments or for regional or basin-wide water resource studies. Graduate school programs in some universities include research in segments of the hydrologic field. Some State water agencies conduct research-type investigations on facets of hydrology. The Forest Service, Geological Survey, Tennessee Valley Authority, and the Bureau of Public Roads are also authorized to pursue various facets of research in the general field of hydrology. The Agricultural Research Service and the Federal agencies mentioned above have representation on the Hydrology Subcommittee of the Federal Inter-Agency Committee on Water Resources where information on programs and activities is exchanged.

REPORT OF PROGRESS FOR USDA AND COOPERATIVE PROGRAMS

A. Precipitation patterns

At Beltsville, a nomogram was developed for estimating the coefficient of variation about the mean of annual precipitation at any point in the continental United States based upon the number of rainy days per year. A map was prepared indicating the geographic distribution of these coefficients. This map, together with a map of average annual amounts, provides practical information on the variation in annual precipitation amounts that might be expected to occur. Such information is useful in connection with many phases of agricultural planning.

At Danville, Vermont, three years of records from the raingage network on the 40-square-mile Sleepers River watershed indicate that individual large storms are not significantly affected by local elevation changes found in this typical upland watershed. Yearly and monthly totals, however, show a definite influence of local elevation changes. Present indications are that average watershed precipitation in this case, with one raingage for approximately each 2 square miles of drainage area, can be calculated without much loss of accuracy by almost any acceptable method.

At Riesel, Texas, frequency analyses of rainfall amounts and intensities indicate that precipitation for the period 1937 through 1960 is about normal in comparison to the Weather Bureau long-term average. The data are being prepared for publication and use in establishing rainfall-runoff relationships. The studies also show that once in 2 years a period of 45 days occurs with less than 0.25 inch of rainfall in 24 hours, and that once in 50 years a 3-month drought occurs. These extensive dry periods normally occur during the growing season and affect crop production.

At Chickasha, Oklahoma, a network of 170 recording raingages, spaced approximately on a 3-mile by 3-mile grid, has been installed on the 1,128-square-mile Anadarko-Alex study reach of the Washita River Basin. The inadequacy of precipitation data with respect to areal coverage is often a primary limiting factor in understanding the hydrologic performance of a watershed or river basin and in developing information on watershed erosion and sediment sources. This network will provide information on rainfall depth-area-duration in the study area for characterizing precipitation patterns of the region.

The raingage network of approximately one recording raingage per square mile on the 93.5-square-mile Reynolds Creek watershed southwest of Boise, Idaho, has provided startling new information on rainfall patterns of precipitation on rangeland watersheds in that area. Records from the few previously existing gages in the region indicate

the 1-hour, 100-year frequency storm on the Reynolds Creek area as 0.50 to 1.00 inch. The network has shown 3 storms on the watershed in the last 2 years that exceeded this, and 10 storms that exceeded the 30-minute 100-year expectancy of 0.50 to 0.75 inch. The areas and intensities of summer storms have been found to be analogous to those in the Southwest. Intensities reached values up to 7.0 inches per hour for short bursts of time up to 10-20 minutes. Storm cells are commonly 2 - 5 square miles in area.

Preliminary observations in the Reynolds Creek watershed in southwestern Idaho, suggest that snow accumulation in areas of rolling or level topography is limited largely by the height of the shrubs, where snow is deep enough to cover the sagebrush. Snow builds up to within about 4 inches of the average height, and additional snow simply blows off. This could have some implications for sagebrush control programs in the higher country, in that complete eradication of the shrubs may adversely affect soil moisture conditions.

The dense networks of recording raingages on the Walnut Gulch watershed, near Tombstone, Arizona, and on the Alamogordo Creek watershed, near Santa Rosa, New Mexico, continue to provide highly significant information on patterns of precipitation on upstream watersheds of the region. In each of the past two years, rainfall intensities for a 15-minute duration have been recorded within two miles of the same point on the Alamogordo Creek watershed which, on the basis of widely scattered Weather Bureau gages, exceeded the amounts estimated for the 100-year event. Such observations dramatize the inadequacies of present information on the rainfall events affecting the hydrologic performance of small-and intermediate-size watersheds in arid and semiarid areas.

B. Soil moisture accretion and depletion

The infiltration capacity of a soil as it changes with continuing rainfall is a most important estimate in computing the hydrologic performance of watersheds. At Beltsville, an analytical technique was developed for determining the potential volume of storage above the impeding strata in a given soil and for estimating the time distribution curve of infiltration capacity as affected by soil moisture and vegetation. The technique will be used in a continuing effort to classify or group major soils of the nation according to their hydrologic potential. Such a grouping would be extremely useful in computations for solution of water-control and related problems encountered in watershed engineering.

At Oxford, Mississippi, an antecedent soil moisture index for loess and associated soils was derived by a simple soil moisture accounting procedure. Potential evapotranspiration was computed by the Hamon formula and adjusted to obtain estimated actual evapotranspiration losses on the basis of available soil moisture in the top

2-foot profile. These losses, used with precipitation and runoff records, successfully predicted continuous daily soil moisture conditions during 1960 on a 3-acre pastured watershed. The neutron meter for measurement of soil moisture was used as a check. Such an index is essential in establishing precipitation-runoff relationships.

It has been demonstrated, at Coshocton, Ohio, that the soil moisture regimen in weighing lysimeters is not always the same as that on adjacent small watersheds. Lysimeter moisture closely agreed with that of the watersheds at high moisture contents but, generally, lower moisture levels were reached on the lysimeters than on the watersheds. The differences were less on well-drained Muskingum silt loam soil than on the Keene silt loam, which has an impeding layer in its profile. Subsurface lateral flow in the watersheds appears to account for much of the deviations. In accounting for disposal of precipitation, these lysimeters gave a more adequate opportunity for checking than did the watersheds, but the water disposal indicated may not be the natural one.

A five-month cumulative record of solar radiation was obtained at three stations in the Santa Ynez River Basin, in the vicinity of Lompoc, California, using experimental distillation-type radiation integrators. Radiation at Surf (1 mile inland from the ocean) was 22% less than at Solvang (28 miles inland) during the period May 9 to July 19, 1961. From July 10 to October 2, when coastal fog was common, Surf received 38% less radiation than the inland station. During the entire 146 days of observation, Lompoc (the intermediate station 8 miles inland) received 13% less radiation than did Solvang. As in previous years a marked evaporation gradient was observed from the sea-coast inland in the Santa Ynez Basin. Evaporation at Surf was only 53% of that at Solvang, but other factors in addition to solar radiation contribute to these differences in evaporation amounts.

C. Ground water accretion, movement and basin recharge

A well point system for *in situ* measurements of permeability was investigated by model studies at Oxford, Mississippi. The method was successfully adapted to deep ground water investigations when used in conjunction with a high velocity, air-vacuum-type drilling rig. Field tests showed wide variation in permeability within a heterogeneous formation but reasonably consistent results were obtained in a homogeneous formation. A report on the study is in press.

Geologic explorations and ground water investigations indicate an outward flow of ground water through the Meridian formation on three sides of the 117-square-mile Pigeon Roost Creek watershed in northern Mississippi. This ground water outflow may account in part for the seemingly low annual streamflow from the watershed and the disparity in rainfall-runoff relationships between some of its sub-watersheds.

The observations further confirm the necessity for an adequate consideration of subsurface phenomena when attempting to explain the effects of land use and treatment measures upon the water budget of agricultural watersheds.

At Chickasha, Oklahoma, core-sampling and the observation of ground water levels indicate numerous confined and hydrologically independent aquifers in the terrace and flood plain areas adjacent to the Washita River. In contrast, the aquifers of residual and colluvial material in the upland areas of the watershed appear to be few, unconfined, and hydrologically interrelated. Such information will be of prime importance in evaluating the influence of watershed protection measures in upstream tributaries upon the water regimen downstream.

Instrumentation has been partially established on the Lowrey Draw watershed in the vicinity of Sonoro, Texas, to provide information on the effects of floodwater retarding reservoirs upon ground water recharge in the Edwards Plateau area. Data are available from only a few runoff events, but in these cases there has been a marked increase in the level of some ground water observation wells associated with impoundments in the surface reservoirs. Much more data will be necessary, however, to define relationships between surface and ground waters in this cavernous limestone region.

Precise definition of the hydrologic boundary of the Reynolds Creek watershed in southwestern Idaho is in progress as a first requisite in accounting for accretions and depletions of the water supplies. Because of the complex geological situation it cannot be assumed that the topographic and hydrologic boundaries are one and the same. Flow directions have been determined in critical areas along the boundary by drilling observation wells. Much of this work remains to be done, as the majority of this area is snow-covered during all but four or five months of the year.

Direct rainfall contributions to ground water are being investigated on sandy soils in the Santa Ynez River Basin at Lompoc, California. Rainfall at Lompoc was 8.03 inches for the 1960-61 water year, 61% of average. This was the third consecutive year of substantially below normal rainfall. Deep translocation of soil moisture (below 20 feet) occurred only on a bare-soil plot. The average depth of rainfall penetration for all plots under native vegetation was about 5 feet. Dry season evapotranspiration rates for the native vegetation plots ranged from approximately 0.01 to 0.03 inch per day, and the comparable rate for a bare-soil plot was in the order of 0.01 inch per day. The native vegetation plots represented grass, brush, and scrub oak complexes.

Two small inexpensive lysimeters were constructed and installed in the Santa Ynez River channel for measuring the rate of evaporation from the dry streambed when the water table is near the surface. The water levels in the lysimeters are automatically maintained at about the same level as the surrounding natural water table. With the water table at 1 foot, the measured evaporation from the river channel near Surf, California, averaged 0.022 inch per day during June and July.

D. Aquifer-streamflow relationships

At Coshocton, Ohio, unit-area surface runoff from 1- to 3-acre watersheds was less than 70 percent of the streamflow from a 75-acre watershed. Return flow from the aquifers accounted for the increase. In some storms the unit-area surface runoff volumes from the small watersheds were considerably less than half that of the larger watershed where the channel is incised into the geologic material. These observations emphasize the necessity of developing information on return-flow phenomena for adequately interpreting the effects of increased infiltration upon flows along the larger streams. How to employ the results of findings on small areas for predicting flow conditions on larger watersheds remains a primary challenge, but obviously the role of subsurface factors cannot be overlooked.

At Madison, Wisconsin, it was found that streamflow estimates for larger watersheds in the Claypan Prairies could be predicted satisfactorily from plot and small watershed data if the plots are of sufficient size and so located to measure subsurface flow. In many cases records from plots and small watersheds represent only surface runoff and are, therefore, of only limited value in indicating streamflow for larger watersheds.

Analyses of 22 years of streamflow records from 481-, 2086- and 3490-acre cropland watersheds near Hastings, Nebraska, indicate that the valley alluviums absorb from about 15 percent of hillside runoff on the 481-acre watershed to about 40 percent of such runoff on the 3490-acre watershed. Thus, these broad, low gradient valleys reduce water yields from their watersheds rather markedly. Understanding the occurrence of such natural abstractions of streamflow is prerequisite background for assessing the downstream effects of upstream watershed programs in this area.

There are many facets to the problem of transmission losses in channels, whether the channels be those of upland draws and creeks or river valleys. At Lincoln, Nebraska, a study of 57 flood events on 18 rivers or large creeks in the Great Plains States showed an average transmission loss of 40 percent of streamflow in an average valley travel length of 57 miles. These losses were found to vary from very small amounts to as much as 75 percent of the flow passing the upper of tandem stream gaging stations.

Research on the hydrologic characteristics of different geologic formations has shown that basalt is apt to be a better structural foundation for stream gages than granite in the Reynolds Creek watershed in southwestern Idaho. This results from the massive nature of the basalt and the presence of shear zones and open-joint systems in the granite which readily conduct water past the stream gage without being measured.

Absorption of storm runoff water by their sand and gravel stream channels is a major factor affecting water yield potentials of upstream arid and semiarid rangeland watersheds. Transmission losses measured in 1961 varied from 5.4 to 18.7 acre feet per mile of channel for single storm runoff events, in a 4-mile reach of channel in the 60-square-mile Walnut Gulch watershed at Tombstone, Arizona. Preliminary geologic investigations indicate that part of this water may be moving downward to the regional water table. Measurements on another reach of the same channel, however, indicate that the underlying aquifer is essentially a large natural lysimeter supporting a dense growth of mesquite. During the growing season, the water level in this latter aquifer drops five to ten times as rapidly as it does during the dormant season. A matter of prime concern is the disposition of these abstractions from streamflow: What portion of this water percolates downward to the regional water table and how much is lost by direct evaporation and transpiration by riparian vegetation?

E. Water yield and water supply and quality

At Beltsville, Maryland, a procedure was developed for estimating annual streamflow for any level of dependability in the unglaciated Allegheny Plateau. The estimating equation considers the drainage area size, average annual watershed precipitation, and a factor reflecting the inherent variability of annual streamflow.

Striking contrast continues to develop in annual water yields of the ten research watersheds located in the Appalachian Valleys and Ridges, Piedmont Plateau, and the Blue Ridge Mountains regions of Virginia. The watersheds range in size from 182 to 3,054 acres. In most cases the differences in rainfall amounts are minor as compared to the variation in the total runoff amounts. Data on soils, land use and physiographic characteristics of the watersheds are being compiled to help explain the differences.

The great disparity in water yields from two adjacent subwatersheds in the Pigeon Roost Creek watershed in northern Mississippi has prompted the initiation of detailed investigations to determine the causal factors. One has a drainage area of 3.13 square miles and the other a drainage area of 1.76 square miles. Each received about 37 inches of rainfall in 1961 but runoff was 22 percent on the

smaller watershed and only about 10 percent on the larger. There is no satisfactory explanation of these differences at present.

Water yield measured as streamflow is noticeably influenced by the seasonal march of evapotranspiration at Coshocton, Ohio. On watersheds there from 29 to 17,500 acres in size, the maximum water yield occurs, on the average, in the period February-April, when evapotranspiration is the lowest. Minimum water yield is observed mostly in the period August-November near the end of the high evapotranspiration period. Average water yield values, regardless of season, generally increase with the watershed size in this area.

At Coshocton, Ohio, pine seedlings planted on a 43.6-acre watershed, in the 19th year of growth, reduced the total streamflow for the year over 5 inches--3.8 inches in the dormant season and 1.7 inches in the growing season. The root system of the pine trees extracted moisture from greater depths than those of the original cover of poverty grass. A cropping system of deep-rooted alfalfa, and with moderately high productivity of corn, wheat, and hay, also extracted more moisture and resulted in streamflow reductions, but the amounts were less. On a 75-acre cropped watershed, the annual reduction by the 19th year was 1.7 inches--1.3 inches in the dormant and 0.4 inch in the growing season.

The Cooperative Water Yield Procedures Study at Lincoln, Nebraska, a cooperative study by the Agricultural Research Service, Soil Conservation Service, and the Bureau of Reclamation, after five years of study, developed and tested a reliable and practical rational method for evaluating the effects of the conservation, use, and treatment of land on water yielded by streamflow of rivers and large creeks in the water-deficient Great Plains. A final report is being prepared for publication which will make the methodology available to such action agencies as SCS, USBR, municipalities, and others who are concerned with the development of works for conserving and using water yielded by streamflow in rivers. Though provisional and subject to revision, the method is thought applicable throughout the Plains area and westward to the California coast, except in the forested mountainous area.

Following several other dry years in western South Dakota, 1961 served to emphasize that stock ponds as presently designed cannot be depended upon to supply water for livestock in parts of the Northern Plains range country. In the vicinity of Newell, South Dakota, where hydrologic studies are in progress, all ponds in the medium-textured soils, and a few in the fine-textured soils area, went dry during the year. Most of those in the medium-textured soils area were dry most of the grazing season. This draws attention to the importance of hydrologic factors in the design of stock ponds. What is the dependable water yield from the watershed and the proper ratio of

storage capacity to drainage area size? What are the rates of seepage and evaporation losses and what can be done to minimize their effects? The data being collected at Newell is helping to answer these questions and provide improved criteria for the design of stockwater ponds in the Great Plains area.

At Riesel, Texas, it has been found that water yield is almost identical to storm runoff in the Blacklands of Texas. Conservation practices in the area affect runoff only to the extent that soil moisture is affected by land use. Analyses are in progress for developing equations and procedures for predicting water yield from ungaged watersheds in the Blacklands area.

In the Western mountains the most important source of irrigation water is from the melting snow pack. An electronic analog has been developed at Moscow, Idaho to facilitate estimates of hydrographs from snowmelt on source areas of the Pacific Northwest. The following parameters are involved: Snow storage and melting as related to climatic, topographic, and vegetational character; losses from evapotranspiration varying with climatic factors; rainfall contribution; soil moisture storage; ground water storage and discharge; and observed streamflow. The analog utilizes the cut-and-try method and is dependent upon the adequacy of existing data, but speeds up the process to the point where it is a practical tool for solving a difficult problem.

Colored aerial photographs are being used as a basis for the soil-vegetation inventory in the Reynolds Creek watershed in southwestern Idaho. For greatest utility in sparse, semidesert vegetation, the photographs should be taken at the time of maximum vegetation greenness. In regions of lush vegetation, however, a more satisfactory time is later in the season when the vegetation has begun to dry but has not completely turned to yellow.

At Lompoc, California, a portable, monolith-type, weighing lysimeter has been designed, constructed and tested in an attempt to obtain an instrument of moderate cost and good accuracy for study of microclimatic influences on net water yields. Performance tests of the prototype electronic weighing device showed that construction of a full-scale field model would be justified. Construction of the full-scale lysimeter and other installations for micrometeorological measurements is in progress at the location.

As is usual in the Walnut Gulch watershed at Tombstone, Arizona, in 1961 all runoff at the five major measuring stations resulted from summer convective storms. It was unusual, however, and contrary to the general experience in arid and semiarid areas, that the seasonal totals and maximum peak rates of runoff experienced this year increased with size of the contributing area. This is, perhaps, attributable to an unusual, but still random, distribution of storms over the watershed

which occurred in a manner to partially offset the effects of high channel transmission losses. This reversal in the usual net effect of size of watershed seems to further emphasize the importance of developing improved capability for rainfall prediction on a watershed basis as one of the factors essential for adequate prediction of runoff from areas of more than a few square miles.

F. Flood flows and storm runoff

An important volume containing basic hydrologic data relating to selected storm events on 67 experimental agricultural watersheds in the United States was released at Beltsville, Maryland. The publication contains tabulations of the following information for each storm runoff event: (1) Antecedent daily rainfall and runoff for 30 days before the event; (2) rainfall intensities and accumulated amounts for the event; (3) runoff rates and accumulated amounts for the event; and (4) watershed conditions at the time of the event. Simple graphs of rates of rainfall and runoff are presented for each event and a map of each watershed is included. For some storms an isohyetal map is also included. The information is of particular value for independent analyses of hydrograph characteristics and their relationships to rainfall and watershed features.

At Beltsville, Maryland, in cooperation with the Soil Conservation Service, the SCS method of storage routing is being adapted and programmed for a digital computer. The completed program will route inflow hydrographs from subareas through reservoirs and stream reaches and the output will be hydrographs at selected points downstream in the watershed stream system. The completed program will be tested against hydrographs observed on Six-Mile Creek in Arkansas. Thereafter, the study will continue toward the development and improvement of the general flood routing technique. Primary efforts will attempt to base flood routing on both the storage equation and the equation of motion.

A 1.5-mile reach of channel in the Sleepers River watershed near Danville, Vermont, with a vertical drop of 200 feet has been selected and instrumented for the study of flood waves in mountain streams. The drainage area is 14.5 square miles at the upper limit of the reach and 16.6 square miles at the lower limit. Controlled flood waves of different volumes will be released from storage above two weirs by means of gates. Studies to date indicate that these mountainous river channels reach a maximum efficiency at somewhat less than bankfull. The relationship between this maximum efficiency, which occurs with the lowest friction slope, and the flow duration curve will be studied. In these studies, the flow duration curve will be plotted in force units instead of rates of discharge, since the channel gradient and size of bed load particles are dependent upon the amount of energy available.

At Coshocton, Ohio, a mthod was developed for computing floodflow volumes and hydrographs likely to be associated with specific estimates of flood peak rates of various recurrence intervals for watersheds of 20 to 20,000 acres. Analyses for development of the procedure revealed that flood peaks per unit of drainage area decreased with increasing watershed size, but that the maximum probable floodflow volumes associated with these peaks were about the same, regardless of watershed size, within the range studied. Data collected at the Coshocton Station over the past 25-year period were used in the analyses.

The fitting of various frequency distributions to hydrologic data has become a widely accepted practice in recent years, but the procedures are usually quite complex. At Coshocton, Ohio, a graphical procedure was developed to facilitate rapid fitting of a wide range of frequency curves to sets of hydrologic data. Exact mathematical procedures have also been developed to refine the graphical fit if desired. A complete description of the development, with the necessary sets of standard fitting curves, has been cleared for publication as a USDA Handbook.

An increase in the amount of cultivated area increases the amount of storm runoff considerably, as indicated by studies on watersheds up to 330 acres in size near Fennimore, Wisconsin, where the soils are a moderately permeable silt loam. A similar change in land use on soils in the Claypan Prairie had only a minor effect on storm runoff. In both cases, the effects of land use diminished as the size of storm increased. Further research is needed to determine how cover affects runoff from other soil types and the limit in size of watershed to which the results are applicable.

At Newell, South Dakota, two unit-source grassland watersheds on fine-textured soils derived from Pierre shale provided runoff data from a thunderstorm of 100-year return frequency. The storm lasted nearly 2 hours with a maximum 10-minute intensity of 3.80 inches per hour. Storm rainfall amounts measured 3.24 and 2.60 inches for the 35- and 115-acre watersheds, respectively. Almost half of the watershed rainfall was accounted for as runoff. The average runoff rate for the maximum 1-hour runoff period was 14.7 c.f.s. on the smaller watershed and 78.8 c.f.s. on the larger one.

At Chickasha, Oklahoma, an analytical study of historical flows on the total Washita main stem is in progress to determine parameters characterizing regime flows prior to development of upstream flood abatement programs and as a basis for a preliminary estimate of changes in flow regime which might result from a maximum watershed development program. This study will also provide a base for comparison with later documented main stem flows in evaluating effects of installed tributary development programs in the Anadarko-Alex study reach. All available measured storm flow hydrographs for main stem gaging stations for the

10-year period 1941-50 are being used in this study. The flow routing constants derived for actual conditions in the period will be used to synthesize new hydrographs for the same storms, but using tributary discharges estimated as if land use and management changes and flood retarding structures were in effect. This exploratory study is being developed in especially close association with the Soil Conservation Service.

For the Blacklands of Texas reasonable estimates of maximum runoff amounts for watersheds up to several hundred acres in size can be made from frequency studies of rainfall, if more detailed runoff data are not available. Analyses of data collected on research watersheds near Riesel indicate that, for return periods of 25 to 50 years, the computed runoff varied from 71 to 83 percent and 73 to 88 percent, respectively, of computed rainfall for the same frequency event. The higher percentages refer to rainfall durations of 1 hour and the lower percentages to a rainfall duration of 8 days. Size of watershed had had little effect on the maximum unit-area runoff on the watersheds involved in this study, which ranged in size from 20 to 1,110 acres.

Research directed at the problem of predicting flood hydrographs and water yield from watersheds in the Pacific Northwest has resulted in the development of three new electronic analogs for the simulation of storage and streamflow. The analogs carry out computations in minutes that would require days by a manual method. A report on this development is being prepared.

On Alamogordo Creek watershed, near Santa Rosa, New Mexico, a violent hailstorm in mid-July produced over 70 percent of the total annual runoff. Runoff from this storm resulted in a flat-topped hydrograph having a peak duration of about 3.5 hours, which is characteristic of flow from the upper part of this watershed. In contrast, runoff from a storm occurring later in the month, but in the southwestern part of the watershed, produced a sharp-peaked hydrograph characteristic of many ephemeral streams in the Southwest. It is believed that flat-topped hydrographs result from the peculiar configuration of the central part of the drainage area where a rock ledge across the drainage backs up the runoff over a wide area and keeps the valley from channeling. This is comparable hydraulically to the water flowing out of a reservoir through a spillway.

G. Criteria for watershed protection

Hydrologic computations involved in watershed protection program planning are being programmed for digital computers through a joint effort of the ARS Hydrograph Laboratory; Soil Conservation Service Central Technical Unit; and CEIR, Inc., a private concern. The program for generation of outflow hydrographs of runoff from source areas, by unit hydrograph techniques, is now ready for testing. When the

hydraulic subroutines have been tested and proved acceptable, the cooperative effort will continue toward the development of concepts and computer sequences arriving at optimized watershed protection programs. Six Mile Creek in Arkansas will be used for testing the optimized computer program as well as the hydraulic subroutines. Hydrologic records and physical data obtained by SCS pertinent to the watershed program installed on Six Mile Creek have been assembled and will be available for this purpose.

During the past year significant progress was made nationwide in adapting mechanical chart readers and high speed computers in the processing and analysis of data on rainfall, runoff, sedimentation and various hydraulic phenomena. There were also important developments in adapting electronic analogs in the solution of hydrologic and hydraulic problems. Use of these techniques and their further perfection will greatly facilitate the handling of large volumes of data and speed up the development of new criteria and guidelines for watershed protection activities.

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AREA 3 HYDRAULICS OF IRRIGATION, DRAINAGE AND WATERSHED STRUCTURES, CHANNELS, AND FACILITIES

Problem. Water control structures of various types represent the largest part of the public and private cost for watershed protection and development programs. They are also essential, but expensive, features for irrigation and drainage developments. Research on the design of water control structures will reduce the possibilities of overdesign, which increases the costs unjustifiably, or underdesign, which may result in costly failure. All items of costs not required for safe functioning of structures must be eliminated. This research includes studies to improve the hydraulic efficiency of items such as: debris guards for drop-inlets, closed conduit spillways; devices for vortex control and dissipation of energy at spillway outlets; cantilevered outlets, drop structures, chutes, sills, etc.; and improved flumes, weirs, gates, and rating sections for streamflow and water discharge measurements. Studies of porous media flow in relation to foundation conditions and the hydraulics of flow in channels and transition sections are included. The hydraulic properties of various grasses and other vegetation in water channels are also determined. It is not possible or desirable to model the many hundreds of agriculture-related water control structures built each year as is the usual custom with the larger dams and spillways on the main river systems. This research, instead, seeks to establish principles and develop dimensionless designs which can be adapted to various site situations and size requirements on individual farms and ranches and in upstream watersheds.

USDA PROGRAM

The Department has a continuing long-term program in which hydraulic engineers are engaged in both basic and applied research on the hydraulic performance and engineering design of water control structures and channels. The studies are oriented primarily to provide information relating to the types of structures and channels involved in group irrigation, drainage and watershed protection activities. The investigations are conducted by means of: mathematical analysis of basic physical principles; studies of models ranging in size from miniatures tested in laboratory flumes to full-size replicas tested in outdoor laboratories; and scientific observations of existing structures and channels in the field. The work is in progress in Arizona, Colorado, Minnesota, and Oklahoma where it is cooperative with the State Agricultural Experiment Stations, and with the St. Anthony Falls Hydraulic Laboratory, University of Minnesota. Close working relations are also maintained with the Soil Conservation Service; Illinois State Water Survey; Minnesota State Highway Department; and Oklahoma State Highway Department.

The Federal scientific effort devoted to this area of research totals 5.8 man-years in the reporting period. Of this number 0.6 is devoted to basic studies of hydraulic phenomena; 4.1 to criteria for hydraulic design of water control structures; 0.3 to hydraulics of waterways and vegetative channels; and 0.8 to flow measurements and water metering devices.

RELATED PROGRAMS OF STATE EXPERIMENT STATIONS AND INDUSTRY

State Experiment Stations in 1961 reported a total of 9.2 professional man-years divided among subheadings as follows: Basic studies of hydraulic phenomena, 4.7; criteria for hydraulic design of water control structures, 1.6; hydraulics of waterways and vegetative channels, 1.6; and flow measurement and water metering devices, 1.3. Basic studies are underway on the hydraulics of sprinklers, the mechanics of water droplet and spray formation, evaporation of water spray, the hydraulic characteristics of the droplets, and on the dynamics of water flow through porous media. The performance of soil and water conservation structures is being investigated through the use of models in an effort to determine causes of failure and to establish adequate design criteria. Research is also underway on the hydraulics of conservation channels and the design of stable irrigation canals to minimize periodic cleaning.

Manufacturing and industrial concerns supply construction equipment, pumps, pipelines and some water metering devices applicable in the installation of irrigation, drainage, and watershed protection programs. Some maintain research functions for the development and perfection of their products. Public construction agencies such as the Corps of Engineers, Bureau of Reclamation and the Tennessee Valley Authority maintain hydraulic laboratories for testing and developing the designs of spillways for individual large dams and for designing improvements and developments along the principal rivers, waterways, and canal systems. Some hydraulic laboratories in universities conduct research in this area as does the Illinois State Water Survey.

REPORT OF PROGRESS FOR USDA AND COOPERATIVE PROGRAMS

A. Basic studies of hydraulic phenomena

At the St. Anthony Falls Hydraulics Laboratory, Minneapolis, Minnesota, several tests were performed to verify the similitude between the water and air models being used for studies of the two-way drop inlet for closed conduit spillways. Entrance loss coefficients obtained from the air tests were compared with those obtained from the water model. This comparison showed excellent agreement, giving experimental assurance to the theoretical prediction that air can be substituted for water to expedite certain tests in the development of water control structures.

At Stillwater, Oklahoma, analyses of 14 experiments on flow over newly emergent vegetation were made to determine the protection offered to channels by these young growths. The data are voluminous and the analyses incomplete, but some preliminary findings can be offered. For example, it was found that a 7-day-old stand of sudangrass could withstand three times the flow rate that a bare earth channel could tolerate. Intensive efforts are being made to relate the dimensions of the plant stems to the flow-retarding properties of the cover. If successful, this will help remove the personal judgment factor from predicting the flow-retarding properties of a vegetation and place the determination on an objective basis.

A single flow event on the specially instrumented reach of Walnut Gulch stream channel at Tombstone, Arizona, afforded usable data for the study of translatory waves. Maximum discharge through the reach was 1,000 c.f.s., with a maximum channel velocity of 8.7 feet per second. Computed critical velocity was 11.3 feet per second. Top-riding translatory waves moved through the reach at rates up to 25 feet per second. These data lend credence to the hypothesis that translatory waves moving on top of established channel flow attain extremely high velocities. Although data are not yet available, waves propagated along a dry channel, the typical condition in ephemeral streams, are of particular interest and will be studied as the opportunity is presented.

B. Criteria for hydraulic design of water control structures

Good progress has been made at the St. Anthony Falls Hydraulic Laboratory, Minneapolis, Minnesota, in determining performance of the two-way drop inlet on a closed conduit spillway. Minimum values of the drop inlet height and length, plate height and overhang, and the maximum plate height that insure satisfactory performance have been determined. Some of the important elements of progress include: (1) A tentative equation giving the crest loss coefficient; (2) a tentative equation for the transition loss coefficient; (3) an equation for total entrance loss coefficient; (4) a general equation for pressure on the crest; and (5) plotting of diagrams showing the location of high and low pressure regions.

Simulated hay trash clogged, to some extent, all the debris guards for two-way drop inlets studied at the Outdoor Hydraulic Laboratory at Stillwater, Oklahoma. The accumulation of trash on the guard reduced the flow capacity of the inlet and as flow duration increased the flow capacity was further reduced. With larger debris guards, which provided a greater net flow area, smaller flow reductions were experienced. A number of guard forms were tested and all performed in about the same general manner. In brief, the flow capacity loss due to debris accumulation was relatively independent of the particular arrangement of the debris guard, but was dependent on the flow area provided.

Comparisons of entrance loss coefficients for the hillside inlet and debris guard and the present two-way inlet and debris guard were made in model studies at Stillwater, Oklahoma. The entrance loss was found to increase with time for each guard type because of the compaction of fibers against the guard, but the new two-way inlet showed much greater hydraulic efficiency.

C. Hydraulics of waterways and vegetated channels

Manning's n values were determined for various channel liners tested for effectiveness in preventing erosion. These studies at Stillwater, Oklahoma, showed that the ranges of n values for the various liners were:

Jute mesh, fine	0.019	to	0.021
Jute mesh, coarse	0.025	to	0.05*
Hay mulch and net	0.08	to	0.16
Paper fiber mesh, fine	0.026	to	0.05*
Glass fiber mat, lengthwise strips	0.013	to	0.015
Glass fiber mat, crosswise strips	0.022	to	0.029

*Large range due to change in channel by erosion.

Manning's n values were also calculated for very young growths of wheat and sudangrass. For the shallow flows these values ranged from 0.035 to 0.12 and increased with increasing flow depth until bending and submergence occurred. For flows above this bend point, the Manning's n values followed the n-VR relationship. For the low flows the n values were influenced by channel bed roughness, stand density, plant form, and planting arrangement.

D. Flow measurement and water metering devices

There is an urgent need for structures or devices to provide precise measurement of streamflow under widely varying discharge and channel conditions. Studies are in progress at Stillwater, Oklahoma, with emphasis on development of flow rate measuring flumes adaptable for ephemeral sand-laden streams. Field surveys were made during the year of a flume site on the Walnut Gulch watershed at Tombstone, Arizona; a flume was designed and a 1:40 scale model was built, with a prototype capacity of 20,000 c.f.s. The setup is ready for laboratory tests. It is hoped that such modeling for individual sites will lead to the development of dimensionless designs and thus reduce the amount of laboratory modeling and rating which is now required.

Extensive studies at Stillwater were made to provide discharge rating information for all ranges of head for various topography conditions and weir changes for the flow measurement station on Switzer Creek in New York State. The investigations revealed that a shorter

crest length would lessen the influence of channel control and improve the sensitivity of flow measurement.

PUBLICATIONS REPORTING RESULTS OF USDA AND COOPERATIVE RESEARCH

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Hydraulics of Waterways and Vegetated Channels

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AREA 4 CONSERVATION OF WATER SUPPLIES FOR AGRICULTURAL USE

Problem. Irrigated agriculture, the largest single user of the Nation's water resources, currently diverts 195,000,000 acre-feet to supply an irrigation requirement of 115,000,000 acre-feet. The difference, 80,000,000 acre-feet, is lost to the farmer largely through seepage, evaporation, use by nonbeneficial plants, and through wasteful runoff during irrigation. Falling water tables are increasing pumping costs and there is danger of depletion over an appreciable area. Ranchers on many rangeland areas need a dependable and economical source of livestock water strategically located for efficient use and maintenance of their grazing lands. The research problem is to develop principles, practices, and equipment for the reduction of water losses, for the development of new water resources, for the recharge of ground water, and for the reclaiming of contaminated and wasted waters for reuse.

USDA PROGRAM

The Department has a continuing long-term program in water conservation involving agricultural and hydraulic engineers, soil physicists and chemists, and geologists who are engaged in basic research for the development of new knowledge and the application of known principles to solution of the farm water problems. Both basic and applied research and development pertaining to the different phases of the water conservation problem are carried on at the U. S. Water Conservation Laboratory, Tempe, Arizona. In Nevada, studies are concerned with use of bentonites for sealing canals and with water salvage from phreatophytes. Ground water recharge, including salvaging of silt-laden water, is under study in California and the High Plains of Texas. Studies in Georgia and Missouri are concerned with the development and sealing of farm ponds. Dug ponds to tap shallow aquifers are included in Georgia studies. Water control and measuring devices are being evaluated in Utah and Colorado. Water harvest is a major project in both Utah and Arizona. Canal sealing by use of chemicals and membranes is under investigation in Arizona and Utah.

The Federal scientific and engineering effort directed to research and development in this area totals 20.9 professional man-years. Of this number 9.9 are devoted to control of seepage and suppression of evaporation from surfaces; 3.7 to development of farm water supplies and related equipment; 6.0 to methods, practices, and devices for ground water recharge; and 1.3 to reclaiming and reuse of wasted or contaminated waters.

RELATED PROGRAMS OF STATE EXPERIMENT STATIONS AND INDUSTRY

State Experiment Stations in 1961 reported a total of 9 professional man-years divided among subheadings as follows: Control of seepage and the suppression of evaporation from water surfaces, 1.6; development of farm water supplies, 4.9; methods, practices, and devices for ground water recharge, 0.4; and reclaiming and reuse of wasted water, 2.1. Monomolecular films for suppression of evaporation from open water surfaces, sealing of channels and reservoirs with colloidal clays, and prefabricated linings for irrigation channels are being studied. Research is being conducted on the development of off-stream pond sites and on storage and management of water for irrigation and other farm uses. Waste water supplies from processing plants are being used experimentally as sources for crop water needs.

Industry and other organizations other than State Experiment Stations are working on monomolecular films for suppressing evaporation, on chemical compounds and membrane materials for sealing canals and reservoirs, and on ground water recharge. Means for maximizing returns for land and water resources are also under study. Estimated annual expenditures are equivalent to approximately 15 professional man-years.

REPORT OF PROGRESS FOR USDA AND COOPERATIVE PROGRAMS

A. Control of Seepage and Suppression of Evaporation from Surfaces

Seepage. At the U. S. Water Conservation Laboratory at Tempe, Arizona, tests have been conducted on various types of seepage meters. The effect of the velocity pattern distortion around a seepage cup on the local head environment of the cup and the direct effect of velocity in a canal on seepage rates were studied in a laboratory flume. Velocity distortion around the cup caused the average head around the cup to be below the free water surface in the canal. Correction factors needed only for low seepage gradients were evaluated and expressed in the form of a graph and a table. Velocity appeared to have no measurable direct effect on seepage, which indicates that evaluating seepage from normally flowing canals by means of still water bodies (seepage cups or ponding tests) is in principle correct.

Theory and principles of the double-tube method for measuring hydraulic conductivity of soil in situ above a water table were tested in the laboratory. The studies, which were carried out in a sandbox, showed excellent agreement between the results obtained with the double-tube and the known hydraulic conductivity of the sand in the box. Equipment and procedures were developed for routine application

of the double-tube method in the field. Of paramount importance in obtaining accurate results is undisturbed, clean soil at the bottom of the auger hole. A special hole cleaner, consisting of a number of parallel, thin steel blades, was developed. The double-tube method combines simplicity of equipment and operation with freedom from stringent assumptions and simplifications. The method is basically sound and the flow system from which hydraulic conductivity K is determined is well defined. Since good results were obtained in the laboratory and field tests, the method appears to be suitable for field measurement of hydraulic conductivity of soil that is not saturated prior to the time of the measurement.

The accuracy of an electrical resistance network was tested for use in analysis of factors controlling canal seepage. The network was temporarily supplemented with resistors in the simulated canal so as to form a system of rectangular geometry. Measured flow rates and potentials were then compared with calculated flow rates and potentials for one-dimensional uniform vertical flow and horizontal flow, respectively. The results showed that the overall accuracy of the network instrumentation was within 0.5 percent, which is more than sufficient for use in water management research.

Laboratory and field studies of soil dispersants and of penetration of sealants into the soil are underway. Four basic formulations and modifications of experimental asphalt emulsions were subjected to exhaustive laboratory and field tests. The materials were applied by spraying and by dispersion in the ponded water. All modifications with solvents, emulsifiers and other additives reduced the effectiveness of the basic formulations, particularly when water temperatures exceeded 90° F. None of the materials penetrated into the soil when applied by the ponding method. All the materials were capable of producing good seepage reduction when properly applied. Spray applications were variable in their effectiveness. These findings indicate that the ponding method of applying these materials, as presently formulated, may be suitable for reservoir linings, but not for conveyance channels. Alternate methods of application, including spray techniques, do appear promising for constructing low-cost ditch linings and are under continuing investigation.

At Reno, Nevada, laboratory studies have shown that 1 pound of Wyoming bentonite for each foot of surface will almost completely seal a 2-inch stratum of medium sand when distributed evenly in the sand. Various bentonite treatments of reservoirs in a field study showed excellent initial sealing with the seepage loss reduced as much as 99 percent. However, after drying for one month and then reponding, the bentonite seal was between 70 and 80 percent effective.

Estimated costs indicate that a bentonite seal could be installed annually at the same cost as a 4-inch concrete liner amortized over a 30-year period at 6-percent interest. Since annual application of bentonite should not be necessary, it appears favorable as a competitive sealer.

At Logan, Utah, laboratory and field testing of a variety of materials for use as canal linings was continued. In a study of rot resistance of lining materials using compost tanks, butyl rubber and polyethylene film were the only materials of the several tested that were not subject to some degradation. All asphalt and vinyl structures tended to harden and become brittle. Degradation of vinyl appeared to be primarily due to the migration of the plasticizer. If biological activity plays a part, it is believed to be a minor one. Coating of jute with asphalt, rubber, or plastics has not effectively controlled rotting, although saturation of the fiber with asphalt did afford some protection. Proofing with copper naphthanate was quite effective, but not to the degree attained with cyanoethylation. Cyanoethylated specimens retained most of their original strength after 2 years in the tanks.

In a study of weather resistance, asphalt and asphalt structures of all types tended to deteriorate rather rapidly. A variety of surface treatments for improving weather resistance including granules, roof coatings, asphalt clay emulsions, etc., were evaluated. Of these, the granules and an asphalt clay emulsion were most effective.

Plastic linings gave almost perfect seepage control throughout test periods of up to 8 years. Even 4-mil vinyl and polyethylene film, properly installed and without damage during installation, provided this level of control. Vinyl linings tended to disintegrate in the area above the water when exposed to the weather. An 8-mil exposed polyethylene liner in a reservoir continuously full of water provided good control for 7 years, although a few small holes developed in the portion above the water, apparently from mechanical damage by birds, animals, or other means.

At Columbia, Missouri, pond sealing studies show that seepage losses from farm ponds in the loessal river-hill areas of the Midwest can be reduced significantly by: (a) Compacting the soil in the bottom of the pond and on the dam to maximum densities; (b) applying a compacted blanket of the silt loam soil or silty clay loam from nearby fields where porous layers are exposed by excavation; and (c) use of chemicals dispersed over the pond surface. For the highly stable aggregated, red clay subsoils of the Ozarks region where suitable blanket materials are not available, it will often be necessary to use both mechanical and chemical methods to obtain a good seal. Both methods of dispersion were effective in reducing

flow through test samples of these soils. Mechanical methods, whether by machinery or the treading of animals, appear to offer the most practical means of sealing ponds excavated in these soils. Tripolyphosphate and hexametaphosphate placed in the soil or in the pond water will reduce seepage, except for extremely high rates of flow; however costs are high. Tests indicated that mixing silt loam blanket materials with the aggregated red clay before compaction would greatly reduce seepage flow. Also, manure added to the pond water improved the seal, although it was not effective for high rates of seepage.

Evaporation. At the U. S. Water Conservation Laboratory, Tempe, Arizona, work has continued on climatic measurements. Several needed instruments were developed. A miniature net radiometer (MNR) was designed, constructed, and evaluated for response to solar radiation, terrestrial radiation, varying angles of incidence, and with respect to time constant, effect of ambient temperature, wind, and weathering. It is a shielded-type net radiometer that utilizes an economical thermal transducer as a sensor. It has several advantages for use in evaporation and transpiration studies. Comparisons of the MNR and a Beckman & Whitley net radiometer were made. An absolute hygrometer, based on the chemical absorption principle was designed and evaluated. In this method a known mass of air is passed through a moisture absorber and the gain in weight is measured to determine the water content of the air. A multiple double-hygrometer was constructed in which the flow at preset intervals could be switched automatically through different pairs of absorption bulbs.

Four experiments were conducted with the weighing lysimeters at Tempe, Arizona, to measure the magnitude and hourly distribution of the components of the energy balance equation over isolated wetted soil surfaces, an extended wet soil surface, isolated shallow water surfaces, and an extended shallow water surface. The results obtained from these experiments indicated that the initial evaporative flux from the isolated wetted soil surfaces was greater than that from the extended wet soil surface. During the large initial evaporative flux from the isolated wetted soil surfaces, energy was derived from the overlying air mass; however, energy was given off in the form of sensible heat to the air from the extended wetted soil surface and from the isolated wetted soil surface when it became dryer. During the initial stages of drying in both experiments, energy was derived from the underlying soil mass. When the soil surfaces became dryer, energy was again utilized in heating the underlying soil mass.

Larger evaporative fluxes were measured also from isolated shallow water surfaces than from the extended shallow water surface. Again, energy was derived from the air for the evaporative process of the isolated shallow water surface, whereas energy was given off in the

form of sensible heat to the air over the extended shallow water surface. For similar energy imputs, larger evaporative fluxes were positively correlated with a greater wind movement. Ratios of evaporative flux to net radiation over the extended wet bare soil ranged from 0.7 to 1.0, the larger ratio being associated with the greatest wind movement over wet soil and the smaller being associated with the drier soil. The ratio of the evaporative flux to net radiation determined over extended shallow water surfaces ranges from 0.7 to 0.8. These ratios indicate that the energy available from net radiation measurements was sufficient to explain the evaporative flux.

Larger evaporative rates were measured from wetted bare soil surfaces than from shallow water surfaces.

Small floating rafts designed to apply chemicals for retarding evaporation from stock ponds were field tested in Nevada, New Mexico, and Arizona. Limited data showed that bacterial action seriously interfered with the operation of the rafts and that corrective measures must be developed. Stranding of the rafts as water levels declined was a problem on some ponds. Alternate methods of material application, possibly in liquid form, will be investigated.

Work has continued at the U. S. Water Conservation Laboratory, Tempe, Arizona, to perfect soil characteristic measurement techniques. A machine was designed and tested which rapidly and reproducibly packs columns with soil at a uniform bulk density. The machine uses a motorized tremie in combination with a motorized vibrator block. A soil column 45 cm. long and 3 cm. in diameter can be packed in approximately 10 minutes with this device. This machine will allow fundamental research on flow of water in soils to progress more rapidly because accurately replicated soil columns can now be prepared.

B. Development of Farm Water Supplies and Related Equipment

Water harvest. A major breakthrough has been made in the field of water harvest at the U. S. Water Conservation Laboratory at Tempe, Arizona. Treatments developed through laboratory and field study include soil stabilizing materials such as asphalt emulsions, and a chemical water repellant for application to mechanically smoothed soils that have been pretreated with chemical soil sterilants. All materials are applied by spraying. Material costs are 5 to 8 cents per square yard and the total cost of initial treatments averages about 10 cents per square yard. Annual costs, including repair treatments, are expected to be about 2 cents per square yard. Assuming 80-percent precipitation recovery, which is realistic in view of measurements to date, the treatments promise to produce water in a 10-inch rainfall area for less than 50 cents per 1,000 gallons.

Data from laboratory and field tests indicate that the initial applications of the soil stabilizing and waterproofing treatments now under test will last well over a year under southwestern conditions of climate and soils. Asphalt emulsions remain the best low-cost soil stabilizing materials tested. One 5- by 20-foot field plot is still producing ten times as much runoff as untreated soil a year after initial treatment, which is the same ratio obtained immediately after application, even though the treatment material was applied at one-half the rate now considered desirable.

Runoff water from the asphalt plots is sometimes discolored and this problem is under study. Weathering properties of the treatment have not been completely evaluated and problems concerned with basic processes of stabilization and waterproofing remain unsolved. Findings to date indicate, however, that the present treatments may now be suitable for operational use on water harvesting installations for stock water supplies.

In Utah, water harvesting tests using ground covers have been underway in the Green Canyon area and in the Fish Lake National Forest near Richfield. Water storage bags made of butyl-coated nylon and vinyl-coated nylon were found to be effective for storing water without loss. Currently, the two most promising materials for ground covers for collecting water are butyl rubber sheeting and an asphalt-coated jute prefabricated canal liner.

Water measurement. New and improved devices and techniques for farm measurement of irrigation water are needed to more efficiently utilize water supplies allocated for irrigation purposes. A vane-type meter developed by the late Dr. Ralph Parshall is now commercially available. Studies at Fort Collins, Colorado, indicate that the accuracy of the device is within ± 5 percent. A greater accuracy cannot be expected because of induced turbulence and the short ditch section in which the meter is suspended. Because it is portable one meter can be used in a large number of prepared boxes for measuring water deliveries.

At the same location, a significant contribution to more accurate water measurement has been made by developing a simplified method to determine effect of submergence on discharge through Parshall flumes. Model studies and examination of previous data have made possible the preparation of rating curves to correct observed discharge for a given submergence. Related investigations have also shown that the convergence angles of Parshall flumes can be changed from the standard of 11°19' to 7°25' with only a 1-percent variation in the head-discharge relationship. Thus, the angle of convergence can be altered within limits indicated to accommodate a particular canal or design without materially changing the rating curve. Considerable savings in future construction costs of measuring sections in canals should be possible as a result of these findings.

At the U. S. Water Conservation Laboratory, Tempe, Arizona, several types of flow meters have been tested. The influence of various factors on the flow rate-pressure differential relationships for centrifugal flow meters constructed from commercial pipe elbows was investigated, including the effect of a 180-degree bend, gate valve position, pressure tap size, and pressure tap location. The test results indicate that standard discharge equations can be used for most 3-inch-diameter, cast, flanged commercial elbows with errors of less than 2 percent at 1.00 c.f.s. and less than 5 percent at 0.10 c.f.s. Deviation due to all flow disturbances tested, including a 180-degree bend, can be reduced below these percentages by 28 diameters of straight pipe upstream from the meters. Size of taps and location of taps are not critical. The elbows do not have to be calibrated in place and can be removed and replaced with no serious effect.

C. Methods, Practices, and Devices for Ground Water Recharge

At the U. S. Water Conservation Laboratory, Tempe, Arizona, a technique was developed for analyzing ground water mound behavior under recharge by use of a resistance network analog. The principles of the technique are applicable to rising, stable, and falling mounds for two-dimensional or radial flow systems. Conditions of nonuniformity in soil conductivity, porosity, and recharge rates as well as complex geometry, boundary, and drainage conditions may be taken into account by the procedure. Moving mounds are handled as a succession of stable mounds. The technique may be used for studies of a general nature where assumed values may be employed. Application of the technique in planning, designing, or analyzing actual installations is only limited by the adequacy with which field information can be obtained.

Experiments at the Ground Water Recharge Field Station in Fresno, California, showed that passing the water through 0.2 foot of filter material reduced the suspended load in the water from 20 ppm to 1 ppm. River water flowing over filter material at a velocity of 0.5 foot per second passed through the filter at more than twice the rate than when ponded on the filter owing to less clogging of the filter material. Filter material was obtained by screening aquifer material obtained from the substrata.

Field studies showed that considerable quantities of water can be percolated through the surface and upper 100 feet of the Panoche soils of southwestern Fresno County, even though the intake rates are low, by flooding for periods of a month or more. Such periods can be coordinated with farm operations during the winter months under current cropping systems. There are, however, perching layers which limit vertical movement below 100 feet. Large-scale recharge in these areas could lead to drainage problems.

In connection with studies at Fresno, California, on recharge of ground water as it affects quality of water, the reliability of the chloride ion as a suitable tracer of water movement was indicated by its close agreement with nuclear probe moisture measurements. Sulfates were leached downward only about half as fast as chlorides. The nitrate ion moved downward at rates intermediate to those of chlorides and sulfates but its movements were somewhat erratic, presumably because of microbial activities.

On irrigated cropland at Lompoc, California, the amount of moisture returned to the ground water table from irrigation and rainfall varied from 1 to 30 percent of the total, with an average of 12 percent.

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AREA 5 IRRIGATION PRINCIPLES, REQUIREMENTS, PRACTICES, AND FACILITIES FOR EFFICIENT USE OF WATER ON FARMS

Problem. The permanence of the agricultural economy of the Western States depends upon irrigation and the solution of unsolved problems associated with the practice. Irrigation has become an important factor in the production of high-value crops in the humid areas where annual or seasonal droughts jeopardize both the quality and quantity of the crop. With the high operating costs of modern farming, crop failures can be disastrous to the farm economy. Currently there are about 32,000,000 acres of irrigated land in the United States. Of these, a little over 90 percent are located in the Western States.

This area of research seeks solution to many of the problems associated with the irrigation practices such as efficient water applicatipn; optimum time and amount of application in relation to crop growth stages; indicators of when to start irrigation; optimum use of limited water; evapotranspiration prediction equations; water intake, transmission, and storage; temperature control; automation; water control equipment; and measurement.

USDA PROGRAM

The Department has a continuing long-term program in irrigation research and development involving soil physicists, soil scientists, and agricultural and hydraulic engineers who are engaged in basic research for the development of new knowledge and in the application of known principles to solution of farm irrigation problems. In Colorado, studies are in progress on the development of a prediction equation for determining evapotranspiration under irrigation using the vertical energy balance approach. New information on consumptive use, irrigation timing, extraction patterns, and crop response are being secured in California, Nebraska, Colorado, Texas, Utah, Nevada, Arizona, New Jersey, Virginia, Florida, Mississippi, Georgia, and Alabama. New studies are planned at other locations. Water intake, transmission, and storage studies are underway in Maine, Georgia, Missouri, Colorado, Texas, Oregon, Utah, Washington, and California. Hydraulics of surface irrigation is under study in Missouri, Colorado, Nebraska, Utah, and Idaho. System design to increase water use efficiency and automation of water application is underway in Colorado, South Dakota, Idaho, Utah, Nevada, Arizona, and California. Irrigation water management for mountain meadows is under study in Colorado and Wyoming.

The Federal scientific and engineering effort directed to research in this area totals 23.7 professional man-years. Of this number, 10.3 are devoted to irrigation water requirements, soil-water relations, and crop response; 5.1 to hydraulics of surface irrigation; and 8.3 to

systems design for efficient use of water and of labor in water application. For effort on quality of irrigation water, refer to Area 7.

RELATED PROGRAMS OF STATE EXPERIMENT STATIONS AND INDUSTRY

The State Experiment Stations in 1961 reported a total of 45.5 professional man-years divided among subheadings as follows: Irrigation water requirements and crop response, 26.1; hydraulics of surface irrigation, 3.1; quality of irrigation water, 1.8; design criteria for more efficient use of irrigation water, 14.5. The response of crops to irrigation water and water requirements are underway for most crops in both the Western irrigated and the humid areas. The work includes the physiology of water movement into and through plants. Research is conducted using the theoretical approach to flow of water in furrows and borders. Automatic control devices are under study. Water quality studies include development of analytical methods for detecting the presence of the newer agricultural chemicals. Studies are in progress to increase the efficiency of surface and sprinkler irrigation systems. Many of these projects are part of a cooperative effort with SWC to solve irrigation problems.

Industrial research in this area is largely for the development of improved sprinkler equipment, pipe, water measurement and distribution equipment, and other accessories. Estimated annual expenditures are thought to be equivalent to about 15 professional man-years.

REPORT OF PROGRESS FOR USDA AND COOPERATIVE PROGRAMS

A. Irrigation water requirements, soil-water relations, and crop response

Consumptive Use, Timing, and Extraction Patterns. Accurate estimates are needed to schedule irrigations, plan more efficient irrigation systems, evaluate water storage requirements, and predict delivery rates for efficient management and utilization of irrigation water supplies. Present methods reasonably estimate the evapotranspiration potential and seasonal use under certain conditions but do not account for variations due to differences in stage of plant development. Results of a 2-year study by the Northwest and Northern Plains Branches relating evapotranspiration rates to solar radiation (short wave) indicate that the vertical energy balance approach to estimate E_t holds considerable promise. Published and unpublished records of evapotranspiration rates ranging from 5 to 20 days were correlated with solar radiation (short wave) measurements available from the U. S. Weather Bureau for a limited number of locations in the 17 Western States. Procedures were developed for estimating solar radiation from readily available cloud cover data for specific periods and for locations where solar radiation data were not available. Results

show the change in the ratio of evapotranspiration to solar radiation as crop cover develops (as with row crops), the maximum ratios for complete crop cover, and the effects of crop maturation combined with reduction of available soil moisture when irrigation ceases. The ratio of measured evapotranspiration to solar radiation provides average values of the combined major variables--reflectance, thermal radiation and sensible heat flux to or from the air--plus other minor components of the energy balance equation. Maximum ratios for complete crop cover compared with estimated net radiation give some indication of magnitude of advective energy in irrigation areas of the West.

During the last three seasons, consumptive use by irrigated alfalfa grown in lysimeters at Reno, Nevada, increased only a small amount as depth to constant water tables increased beyond 2 feet. There was no yield effect. Within the depth studied, alfalfa adapted well to the constant-depth water tables. Consumptive use correlated positively and significantly with growth stage. At Lompoc, California, consumptive use by alfalfa increased as distance from the ocean increased from 5 to 28 miles. This was partially explained by difference in solar radiation. At Weslaco, Texas, water use by irrigated cotton increased from 0.04 inch per day during the first 6 weeks after planting to 0.18 inch per day during the 3-month fruiting period and then dropped to 0.07 inch per day during the harvest period. Peak rates for very short periods with high soil moisture were more than twice the average during the fruiting period.

Grain sorghum showed a consumptive use rate during the peak growth period of 0.18 inch per day under field conditions at Watkinsville, Georgia, and rates of 0.27, 0.17, and 0.15 inch per day in lysimeters with water table depths of 12, 24, and 36 inches, respectively, at Fort Lauderdale, Florida. A predictable relationship of evapotranspiration from cotton and Coastal Bermudagrass to open pan evaporation was shown at Thorsby, Alabama. Interaction effects of soil moisture and nitrogen levels were very pronounced on flue-cured tobacco production at Tifton, Georgia. Best per acre returns and quality of product were obtained from an applied nitrogen level of 70 lb./acre and a soil moisture stress not to exceed 0.8 atmosphere in Tifton loamy sand.

A lysimeter study in New Jersey showed evapotranspiration for cabbage ranged from 0.10 to 0.24 inch per day from June through July. An increase in soil-water tension was accompanied by a decrease in the evapotranspiration rate. In the humid area, crop response to irrigation depends upon amount and distribution of growing season rainfall. During 1961, irrigated cabbage outyielded the nonirrigated by 5.4 tons per acre or 25 percent, whereas there was no response with sweet corn, muskmelons, and snap beans. In Virginia, yield response of bermudagrass to irrigation increased with increased use of nitrogen within the range studied and with improved cutting management

consisting of taking the first cutting at early head stage and subsequent cuttings at a 10-inch height, but always cutting a stubble height of 4 inches.

In a mountain meadow study in Colorado, continuous irrigation and low fertility reduced a timothy sod to a poor quality, grass-sedge-rush complex within 2 years. At high nitrogen levels and good water management the timothy persisted and yields were increased sevenfold.

Water Intake, Transmission, and Storage. At Davis, California, a controlled laboratory study of cylinder infiltrometers ranging from 6 to 20 inches in diameter with coarse-textured, fine-textured, and layered soils was completed during the year with the following conclusions:

From measurements of pressure under cylinder infiltrometers and calculations of hydraulic head, the flow regime was found to be radial in character regardless of the size, ratio of size, and number of buffered cylinders, or the media in which the cylinder infiltrometer was tested. The suction and hydraulic head decreased logarithmically from the center to the outer edge of the flow regime. The only vertical flow was that particular streamline from the exact center of the infiltrometer cylinder. This difference in potential or suction produced a lateral gradient resulting in a higher rate of flow into the soil near the outer edge of the cylinder. This, with the accompanying increase in the horizontal area through which the flow passes as the cylinder size increases helps to explain variation in results from infiltrometers with different diameters. An increase in hydraulic head resulted in an increased infiltration rate.

All sizes of infiltrometers tested overestimated the one-dimension flow rate. The infiltrometer-measured rate in sand for the 6-inch-diameter single cylinder was at least three times the one-dimension value as compared to the overestimation of the one-dimension rate of 183 percent in the inner compartment of a 22-inch buffered infiltrometer. In Columbia silt loam the 6-inch-diameter single cylinder also overestimated the one-dimension flow of this soil by about 25 percent. Similar measurements in layered soils, where the less permeable layer was at some distance below the infiltrometer, show that the infiltration rates were not the same as the one-dimension flow in either of the two single soils which comprised the two-layered system.

The results indicate that each different size infiltrometer, buffered or not, will require a different "correction factor" multiplier to estimate the one-dimension flow. Therefore, for the media tested and for the conditions pertaining to this experiment, no advantage is shown for the use of buffered over unbuffered cylinders. As infiltrometers, buffered cylinders merely require a "correction factor" of lower magnitude.

Since flow rates in the larger diameter infiltrometers were found to be more consistent and more nearly approached the one-dimension infiltration rate of each media, recommendation can be made for size as follows: In the case of a buffered cylinder infiltrometer, the inside cylinder should be at least 10 inches in diameter and the outside cylinder 18 inches in diameter. For a single cylinder infiltrometer, the minimum size should be about 20 inches in diameter.

Soil compaction by equipment travel seriously reduces infiltration of irrigation water. Orchards are especially affected because of numerous spray operations using heavily loaded rigs. An evaluation of an 8-year cover crop study at Prosser, Washington, showed that the 24-hour cumulative intake was 45 percent greater with a cover crop of continuous orchardgrass or alfalfa as compared to bare or disked rye treatments in traveled areas.

Field capacity values are used extensively in irrigated system design and operation. Drainage of soil by gravity decreases with time because unsaturated hydraulic conductivity decreases as the soil becomes drier and soil moisture suction increases. Studies on synthetic soil profiles at Prosser, Washington, have shown that the "field capacity" of soils will be much greater if the soil is underlain by a coarse sand or gravel layer. Therefore, laboratory methods using composited samples are unreliable for estimating field capacity when soils are stratified.

As part of a program to evaluate the water-holding capacity of benchmark soil types, 51 soil profiles representing 23 soil types in Maine were characterized for water retention values. A study relating water-holding capacity to various textural components revealed that water retention was more closely correlated with the silt content of these soils than with any other size fraction.

B. Hydraulics of surface irrigation

Rational design and efficient management of surface irrigation systems require knowledge of the hydraulics of flow over plain beds and in furrow-shaped channels. Laboratory and field studies of the problem have been in progress at five locations. In Colorado and Missouri, laboratory studies have utilized boundary and channel models and in Idaho a Hele-Shaw apparatus. The studies in Utah were concerned with field furrows and those in Nebraska with low gradient border checks. Significant progress has been made in each phase of the study although none have been completed.

A Hele-Shaw apparatus consisting of two closely spaced glass plates with glass fiber filter material in the lower half to simulate intake was used with a viscous fluid to simulate open channel flow in an irrigation border at Boise, Idaho. Dimensional analysis of the initial

data combined with multiple regression techniques produced an empirical equation for predicting rate of advance using the variables: Cumulative intake at the upper end of the border, stream size, border width, time, viscosity of the fluid, a roughness factor, and slope. This equation predicts rate of advance with reasonable accuracy in the model for steeper slopes. For flatter slopes, predicted rates of advance are generally too great or too small, depending on the stream size used. These equations will be tested in the field in 1962 to determine the suitability of using the Hele-Shaw apparatus to simulate flow of water through close-growing crops in irrigation borders where intake rates change with time. If the model adequately simulates border flow and intake, fundamental relationships of hydraulics of border irrigation can be obtained from further model studies.

Hydraulic studies at Fort Collins, Colorado, have provided empirical equations for predicting friction factors for laminar flows over rough boundaries. Factors of roughness, height, and spacing, which cause greater resistance to laminar flow than predicted by theoretical formulas for smooth boundaries have been established. Verification of formulas under field conditions is needed.

In Missouri, studies using furrows with a V-shape and a 20-inch-wide, flat bottom showed that roughness was a function of the flow depth in both shapes, such that greater depths resulted in lower values of Manning's "n". The magnitude of "n" and its relation to depth appeared to be about the same for the two shapes with both uniform and nonuniform flow. The rate of advance equations for uniform and nonuniform flow changed with slope. With high application rates, the 20-inch flat bottom furrow with either flow had a higher rate of advance than the V-shape furrow, but at low application rates the reverse occurred. The intake phenomenon did not affect rate of advance after the application rate per minute in either furrow shape. The Reynolds numbers for both furrow shapes and all velocities were in the transition and turbulent range. The Reynolds number for a V-shape furrow was approximately two or three times the value for a 20-inch flat bottom furrow.

Data collected in the Logan, Utah, field irrigation furrow study did not follow the generally accepted rate of advance equation, $X = gT^a$, where X is the distance in feet traveled by the water in T minutes, with g and a constants, but took the form, $T = a\text{-}ae^{cX}$, where T is the time in minutes required for the water to travel a distance X. The constant e is the base of the natural logarithm with a and c constants determined from the data.

In the field study of low gradient border checks on a sandy soil at Scottsbluff, Nebraska, data from alfalfa borders have shown that the volume of water temporarily stored on the surface of the soil during the advance of the border stream can be predicted within 5 percent of

measured values if accurate intake data are available. These predictions were obtained using cumulative intake data obtained from five cylinder infiltrometers combined with rate of advance data. These results indicate that rational design procedures for low gradient irrigation border strips are feasible but will be greatly dependent on accurate intake rates for the first 1 to 2 hours.

C. Systems design for efficient use of water and of labor in water application

Water Use Efficiency. Results of studies concerned with the operating characteristics of low gradient irrigation borders cropped to sugar beets, dry beans, alfalfa and corn on Tripp fine sandy loam at Scottsbluff, Nebraska, indicate that irrigation application efficiencies of 90 percent can be achieved on level and low gradient border strips if stream size is adjusted to border width and length in relation to stage of plant development. Where crop retardance was low, equal intake opportunity time was possible on 0.02 to 0.04 percent gradients up to 700 feet long using a stream size equivalent to 0.045 c.f.s. per foot width of border. Stream sizes of 0.045 and 0.075 c.f.s. per foot width of border were adequate on 0 to 0.04 percent gradients for corn, alfalfa and dry beans but not for sugar beets. Modifications in low gradient irrigation systems to increase application efficiency under conditions of high crop retardance are possible by not backfilling the small ditch that remains after plowing on the edge of the border, thus allowing for rapid delivery of water throughout the irrigation run. Crop performance on low gradient systems was excellent for corn, alfalfa and sugar beets where ridges and part of the crop were inundated at each irrigation. Dry beans did not yield as well as the same crop grown under conventional furrow irrigation.

A low-cost surface irrigation method for irrigating steeper slopes immediately above the wet mountain meadow areas of Colorado shows promise of more efficient utilization of irrigation water supplies. Guide borders and border strips individually prepared with standard equipment permit minimal movement of surface soil to eliminate side slope and facilitate uniform distribution of water. Runoff is eliminated by concentrating waste water in level collection basins at lower end of the field. The irrigation system developed is highly efficient as indicated by the first year's return of 3 tons of alfalfa-brome produced with 16 inches of applied water. In contrast, 25 to 50 times this amount of water is normally applied to adjacent wet meadows. Other advantages of the irrigation method include lower construction cost, about 15 times less than adjacent field leveled by conventional procedures, and reduction of the waste water source associated with mosquito propagation.

An irrigation experiment involving potatoes on the High Plains of Texas showed that a higher irrigation application efficiency was achieved with alternate-row rather than every-row irrigation. Potato yields were highest, however, in the high-moisture plots in which the every-row irrigation was combined with the technique of continuing furrow flow until blacking out the beds through wetting action has been completed.

Border-irrigated alfalfa at Lompoc, California, produced a little over 1 ton per acre for each inch of evapotranspiration. Highest water use efficiency was usually at points receiving the least water and fartherest from the water application end of the border.

At Boise, Idaho, in a study of sprinkler irrigation patterns as related to water application efficiency, an average of 87.2 percent of the water delivered by the sprinkler system could be accounted for by catch cans. The remaining 12.8 percent was considered lost by evaporation from the spray. The loss computed by the Frost-Schwalen method developed for estimating evaporation in Arizona was 41 percent less, indicating that an improved method may be needed for conditions encountered in the Snake River Valley.

Automation. Public patents are now pending for the automatic water control gates developed at Boise, Idaho. Field testing during the year resulted in a number of improvements that were incorporated before patents were applied for.

Limited Irrigation Water Supply. In a study of factors affecting irrigation efficiencies in Escalante Valley, Utah, a new criteron, "farm efficiency classification," was developed as a means of evaluating irrigation operations. Farm efficiency classification is a comparison of farm operations based on water rights and irrigated acres. Within the limits of the water right and the acreage for which water rights are held, an individual farmer can make adjustments to avoid overpumping his alloted water. Irrigation efficiencies are increasing in the Valley where legal restrictions have limited the water supply.

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AREA 6 DRAINAGE PRINCIPLES, REQUIREMENTS, PRACTICES, AND FACILITIES FOR PROTECTION OF CROPS AND SOILS

Problem. Water management systems have been applied to some 140 million acres of potentially wet lands in the United States. Over 90 million acres are in organized districts and the remainder are individual farm enterprises. Water management problems on these lands include: High water tables that restrict root development during the spring and consequently lower the plants' drought resistance during dry periods that generally follow; flat poorly drained areas with microtopographic variations that pond water, delay planting operations beyond optimum dates, and make use of modern farm equipment uneconomical; hillside seepy areas that function similarly to reduce farming efficiency; and the vast irrigated area of the arid West with over 50 percent of the acreage needing drainage to prevent salting out and eventual abandonment.

This area of research seeks to determine the drainage requirements of crops under different soil and climatic conditions and to develop design criteria for both surface and subsurface systems to meet these requirements in a practical and economical manner for each of the four types of drainage problems.

USDA PROGRAM

The Department has a continuing long-term program in drainage research and development involving soil physicists, soil scientists, plant physiologists, and agricultural and hydraulic engineers who are engaged in basic research for the development of new knowledge and in the application of known principles to solution of farm drainage problems. Research is underway on surface drainage, including land forming, in Virginia, Louisiana, and Minnesota. In the area of new materials and equipment for installation of subsurface drains, work has been largely confined to plastic mole drain liners. Development work is in progress in Ohio. Trial installations are under observation in Louisiana, Minnesota, Colorado, North Dakota, Utah, Nevada, California, and Florida. Tile filters are under study in California and the hydraulics of tile fittings in Minnesota. Interception drainage of sloping lands is being investigated in Vermont, New York, and Ohio and interception of water under hydrostatic pressure in Wisconsin and Oklahoma. Irrigation drainage and drainage for salinity control is studied in California, Colorado, Texas, Nevada, and North Dakota. Research is in progress in Florida and North Carolina on drainage requirements of crops. Work on water transmission, measurement, and soil properties related to drainage is in progress in Colorado, Ohio, and Georgia and on system performance in New York, Ohio, and Minnesota.

The Federal scientific and engineering effort directed to research in this area totals 18.5 professional man-years. Of this number, 2.2 are devoted to surface drainage -- land forming, drain depth, spacing and conveyance; 3.4 to subsurface drainage -- new materials, techniques, equipment and hydraulics; 2.5 to interception drainage; 4.0 to irrigation drainage and drainage for salinity control; and 6.4 to design of optimum systems for water table control.

RELATED PROGRAMS OF STATE EXPERIMENT STATIONS AND INDUSTRY

The State Experiment Stations in 1961 reported a total of 16.7 professional man-years divided among subheadings as follows: Land forming, drain depth and spacing, and conveyance requirements of surface systems, 6.1; new materials, techniques, and equipment for subsurface systems, 5.1; interception drainage on sloping lands, 0.3; drainage of irrigated lands, 3.6; and design of optimum drainage systems, 1.6. Land shaping is being studied for improvement in surface drainage with particular attention to surface drainage of impermeable lands. The use of envelope material around drains and the feasibility of small, high-speed pipe laying machinery for installation of lateral drains is being studied. Field terraces are being investigated for interception drainage and for the diverting of hill runoff from bottom fields. Research is underway on more effective maintenance to improve conveyance. Basic research on the dynamics of water movement in soils and into drains is underway. A part of this research is in cooperation with the Agricultural Research Service.

A number of industrial companies are engaged in the development of plastic and other materials for subsurface drainage lines, drain line envelopes, machines for installation of drain lines, and for land smoothing. This is largely applied research and development. Estimated annual expenditures devoted to this work are equivalent to approximately 10 professional man-years.

REPORT OF PROGRESS FOR USDA AND COOPERATIVE PROGRAMS

A. Surface drainage -- land forming, drain depth, spacing, and conveyance

In Virginia, land forming to remove microtopographic variations and establish a uniform grade of 0.10 percent on a river bottom soil has resulted in about doubling of the production efficiency. Yields on cut areas were only slightly lower than those on fill areas. Similarly, land forming in the sugar cane and cotton lands of Louisiana have greatly improved water management and enabled more efficient use of crop production equipment. Row grade and length studies are underway for these soils. In Minnesota, studies have shown that the cost of construction, depth of topsoil removal, and depth of available outlets are significant factors affecting the selection of the optimum

grade and length of row when land forming in the Red River Valley. Neither crop yield, average soil moisture, or soil temperature was significantly affected by grade or length of row. Land forming in the Red River Valley has improved farming efficiency by eliminating small ponded areas within cultivated fields. Seeding was possible earlier in the spring and tillage was possible sooner after rains. By increasing yields on formerly depressed wet areas and permitting more timely farming of the remaining areas in the field, field yields were increased.

B. Subsurface drainage -- new materials, techniques, equipment, and hydraulics

In Ohio, one year of field use shows that the zipper-type plastic mole liner maintains its cross-sectional shape and size better than the plain overlap or capped overlap types of mole liners. Unlined mole drains were plugged by loose soil falling from the drain channel walls within 1 month after installation.

Closing the soil slit left by the mole drain machine by one pass of a crawler tractor track was beneficial to mole liner durability. After one season, sections of plastic-lined moles where the slit was closed immediately after installation were larger in cross-sectional diameter than were those sections of the drains where the slit was not closed. Almost all lines installed only 12 to 16 inches below the bottom of field ditches, or open plow furrows in soils other than muck, were damaged or partially collapsed. On muck soils, damage occurred to lines installed at depths of 24 inches or less. The average flow rate with sprinkler irrigation application from 3-inch-diameter, plastic-lined mole drains was essentially the same as from 4-inch tile drains when compared on the basis of flow per unit length of drain.

Performance studies of plastic liners with overlap joints in Minnesota, Florida, Louisiana, North Dakota, Nevada, and California showed impaired functioning due to partial clogging or collapse after one to three seasons of use. Test liners installed in Utah and California, however, continued to function satisfactorily through three seasons.

A pendulum mechanism used as a slope-sensing device served quite satisfactorily in Ohio as the basic principle of an automatic grade-control system for a floating-beam-type mole drain plow and for a wheel-type tile trenching machine. The major limitations of the automatic grade-control system on the Saveson floating-beam mole plow was that the hydraulic depth-control system could not respond rapidly enough to the commands of the grade-control system when crossing surface depressions. As depth of operation was increased, draft requirements increased and the problem was magnified. A new mole plow

was designed with an improved draft linkage mechanism to overcome these difficulties.

The operation of the pendulum automatic grade-control system was very satisfactory on the trenching machine. Close tolerances with preset drain gradients were secured.

At Brawley, California, laboratory studies of fiberglass filters have shown that both the filter thickness and hydraulic conductivity decrease exponentially with increased loading on the filters. While definite information is not available on the magnitude of the load and compression of the filter, there is indication that the 1-inch mats are compressed to a thickness of between 0.1 and 0.2 inch.

At Weslaco, Texas, a pitot tube air meter was successfully developed and calibrated for measuring flows in buried tile lines. The meter is sensitive to low flow velocities and is accurate through the range of 2 to 40 gallons per minute.

C. Interception drainage

A survey of existing diversion terraces was made in New York to evaluate the factors affecting the efficiency of these structures in control of hillside seeps. Seepage was more prevalent on the Lordstown-Volusia soil association than on the Volusia-Mardin or Erie-Landford associations. In general, there was less evidence of seepage, which suggests better control, on steeper slopes where steeper channel grades were used. The older diversions were less effective than newer ones, largely because of a lack of maintenance. A controlled evaluation of diversion terraces for interception drainage, with and without tile drains, is being carried on in Vermont. Piezometers are used to determine the directional components of subsurface water flow on a wet, seepy hillside. Data available at this time indicate the flow is largely parallel to the land surface but with some downward movement. Upward movement during the wet part of the year is indicative of limited artesian pressures in the Cabot soil.

D. Irrigation drainage and drainage for salinity control

Investigations at Weslaco, Texas, of several tile systems in irrigated areas of the Rio Grande Valley indicate that failures and poor functioning of tile systems were caused by: (1) Improper tile spacing; (2) incorrect installation procedures; (3) placement of tile lines in relatively impervious material; or (4) lack of proper maintenance. Fluctuating water tables in the area were caused by excessive irrigation and rainfall.

Recent studies in both Texas and California suggest that deeper placement of tile in irrigated and dryland areas of the West may have

several advantages. Electric drainage analogue studies were used at Weslaco, Texas, to determine water flow characteristics through a typical stratified soil in the dryland "hot spot" problem area of the Lower Rio Grande Valley. The soil has a hydraulic conductivity of 3.0 inches per hour to a depth of 8.0 feet and a conductivity of 30.0 inches per hour in the 8- to 30-foot depth interval. The analogue solutions show a theoretical fourfold increase in the flow to a completely porous tile line when it is placed at a depth of 10 feet rather than 6 feet, a frequently used depth in this area. Several tile lines will be installed in the field to test the results of the analogue studies.

At the U. S. Salinity Laboratory, Riverside, California, studies of three methods of measuring evaporation of water from soils that are partially waterlogged have shown general agreement among the methods. Evaporation of water from soils results in salinization as well as loss of valuable water. Quantitative information on the magnitude of such losses is limited. The methods being evaluated are: (1) A theoretical method, which involves a calculation based upon both laboratory and field measurement of pertinent physical quantities; (2) an indirect method involving the rate of accumulation of salts in the surface soil; and (3) the evaporimeter method, which gives a direct measure of water movement upward from a water table.

The laboratory determination of capillary conductivity for the theoretical method, generally considered difficult, has been simplified by a technique developed to measure and record small flow rates. Average values of water loss over long periods are obtainable by the salt accumulation method, but soil variability and other factors make this method less desirable than the other two. The evaporimeter method, which gives a direct measurement of movement upward from the water table, permits measurements to be made for much shorter time periods (weekly) and when the installation is properly made, reliable results are secured.

Evaporation measurements at a field site in the Imperial Valley, California, show a loss of 0.036 inch per day or 13 inches per year for a fallow soil with a water table at a depth of 5 feet. When weeds were allowed to grow, the rate of water movement upward from the water table increased to 0.145 inch per day or 53 inches per year. These results show that significant amounts of water are lost from water tables that are maintained at a depth generally considered adequate from the standpoint of drainage. The desirability of deeper depths is suggested.

In Imperial and Coachella Valleys, the problem of tile clogging with manganese and iron oxides has become more critical. A comparative study of reducing agents at Pomona, California, revealed the presence of large reserves of easily reducible iron and manganese in

two Imperial Valley soils where iron and manganese deposits were known to occur in tile systems. When these soils were leached under reducing conditions, 1.53 pounds of iron and 2.61 pounds of manganese were removed per acre-foot of leachate; however, with the addition of nitrogen fertilizer, the amounts were 0.85 pound of iron and 4.12 pounds of manganese. It appears that conditions effecting an increase in manganese solubility may cause a decrease in the solubility of iron. Also there was evidence that organic matter and biological activity may stimulate the rate of the reaction.

At Weslaco, Texas, photogrammetry and spectrophotometer studies concerned with early detection of potential drainage and salinity problem areas revealed marked differences in spectral reflectance between saline and nonsaline soils in the wavelength range of 325 to 800 millimicrons. Similar studies of citrus leaves from trees affected by salt concentration and high water tables showed increased reflectance by affected leaves in the wavelength range of 550 to 675 millimicrons. Film-filter combinations were selected to obtain maximum contrast for aerial photographic identification of affected areas. Aerial photographic surveys permit early detection of high water table saline problem areas. Highly saline areas, locally called "hot spots", contain high salt concentration in the surface soil with decreasing concentration with depth. Transitional problem soils where plants barely survive contain salt accumulation at depths of 2 to 4 feet. In soils supporting normal crop growth, salt concentrations are below the 4-foot depth or do not exist. Photogrammetry and spectrophotometer studies are potentially useful in estimating salt concentration severity on affected soils and the need for drainage and other treatments.

E. Design of optimum systems for water table control

Drainage Requirements of Crops. Studies in North Carolina with controlled water tables and plant environment showed that growth of soybeans was inversely proportional to depths to water tables that ranged from 6 to 36 inches when the controlled ambient temperature was 72° F. At 80° F., growth was directly proportional to depth to water table, and at 90° F., growth was not affected by depth to water table. Leaf temperature of soybeans was not affected by water table depth. Grain sorghum, string beans, sweet corn and dwarf field corn all demonstrated optimum yields at water table depths of 24 to 30 inches, but fescuegrass was little affected by water table depths. Protein and fat contents of grain from sorghum and corn were not affected by depth to water table. Oxygen diffusion in the primary root zone of the crop was quite good where the water table was maintained 18 or more inches beneath the soil surface.

Water Transmission, Soil Properties, and Related Instrumentation. Characterization of porous media with respect to the functional relationship between capillary potential, permeability, and saturation

has a practical application in predicting the flow of water in soil above the water table and in defining the drainage capabilities of a soil. In addition, the height of the capillary fringe as related to aeration from the standpoint of water table depth required to maintain a favorable environment for root growth can be predicted. At Fort Collins, Colorado, theoretical formulas based on the parameters indicated above have been verified using many different types of unconsolidated porous media. Preliminary data agree very well with theoretical equations developed, indicating that physical significance can be attached to parameters in the equation to characterize porous media with respect to hydraulic behavior. A method for measuring gas permeability as a function of capillary pressure and saturation has also been developed and appears to be a usable technique for predicting liquid permeability as a function of capillary pressure and of saturation.

Studies at Fleming, Georgia, of soil-water relationships show the sandy soils of the lower Atlantic Coastal Plains have very low water-holding capacity. This suggests that excessive drainage of these soils should be avoided, and that consideration should be given to drainage systems designed to facilitate the application of irrigation water during drought periods.

Systems Performance. In many areas subsurface drainage systems have been installed without the support of surface systems. On some soils, subsurface systems have become less efficient with continued row crop farming or what was considered poor crop and soil management. These and related problems have been under study in Ohio and New York.

In Ohio surface, subsurface, and combinations of both drainage systems were studied by applying simulated rainstorms totaling 3.9 inches at intensities of 0.23 and 0.51 inches by use of sprinkler irrigation equipment on grass cover plots. Surface drainage reduced tile flow volume about 43 percent, and tile drains reduced surface flow runoff about 40 percent. Based on water table, soil moisture, and other measurements, the combination tile and surface-drained plots had the best drainage, while the surface-drained only and tile-drained (level) only plots had about the same degree of drainage. High antecedent moisture increased the tile flow volume 100 percent and the surface runoff volume more than 150 percent. Peak tile flow was increased only slightly and peak surface runoff was increased about 20 percent. Doubling the rate of water application increased the peak tile and surface flow rates, but had little effect on the volume of flow.

In a comparison of good versus poor cropping management systems on a poorly drained soil in New York, greater peak tile flows occurred under the good management system, suggesting that water transmission is affected by management.

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AREA 7 SALINE, SODIC, AND RELATED SOILS PROBLEMS, AND QUALITY OF IRRIGATION WATERS AND THEIR RELATION TO PLANT GROWTH PROCESSES

Problem. Salinity is a major problem in irrigated agriculture. In the arid West, injurious concentrations of salts in the soil have impaired the use of 25 percent of the irrigated land. Fifty percent of this area is endangered. These salts move upward in the soil with water to supply evapotranspiration requirements and are left behind as the moisture passes into the atmosphere. This results in injurious accumulations in the root zone unless excess water is periodically passed downward to leach the salts to the ground water or to a tile drainage system for removal in the tile effluent. Control of salinity and the reclamation of salty soils involves many complex physical and chemical problems which can be attacked best by the development of basic information on the relations of saline irrigation water, salt-affected soils and plant growth processes. From this information application techniques for diagnosis and improvement of specific field conditions can be developed.

USDA PROGRAM

The Department has a continuing long-time program for coping with saline and sodic soil and quality of irrigation water problems involving physicists, chemists, soil scientists, plant physiologists, agronomists, and agricultural engineers who are engaged in basic research for development of new knowledge and in the application of known principles to solution of farm salinity problems. The center for basic research in salinity is at the U. S. Salinity Laboratory, Riverside, California. There are 21 professional employees at this location with 17 engaged in the different phases of salinity and the others in closely related fields of soil-water relations and drainage. Studies dealing with mechanisms of reactions of importance in salt-affected soils and waters and diagnostic techniques are underway at the laboratory and also in Virginia and Texas. Those concerned with physiological basis for tolerance of plants, and adaptation and response of plants to salt-affected soil and water, are underway at the laboratory, and in Virginia, New Jersey, Georgia, and Texas. Studies dealing with water composition and reactions occurring when salt-affected soils are irrigated and drained are in progress at the laboratory, and in Virginia, Texas, and California. Studies of crop and soil management systems for various levels of salinity and sodium saturation of soils are underway in Oregon, Texas, and North Dakota. Reclamation by leaching is under study at the laboratory and in Montana and Texas.

The Federal scientific and development effort directed to research in this area totals 22.2 professional man-years. Of this number, 8.0 are devoted to mechanisms of reactions of importance in salt-affected soils and waters and diagnostic techniques; 7.5 to physiological basis for tolerance of plants, and adaptation and response of plants to salt-affected soil and water; 3.5 to water composition and reactions occurring when salt-affected soils are irrigated and drained; 1.6 to crop and soil management systems for various levels of salinity and sodium saturation of soils; and 1.6 to reclamation by leaching.

RELATED PROGRAMS OF STATE EXPERIMENT STATIONS AND INDUSTRY

The State Experiment Stations in 1961 reported a total of 9.8 professional man-years divided as follows: Mechanisms of reactions of importance in salt-affected soils and waters, 1.9; physiological basis for tolerance of plants and adaptation of plants to salt-affected soils and waters, 0.8; reactions occurring when salt-affected soils are irrigated and drained, 3.0; crop and management systems for various levels of salinity and sodium saturation of soils, 3.9; and reclamation by leaching, 0.2. Most of this research (8.8 man-years) is located in the Western States and the remainder in the Southern States. It is frequently in close cooperation with Federal work and is coordinated with the work at the U. S. Salinity Laboratory by their biennial cooperators' meetings.

Information is not available indicating research in the agricultural phases of salinity by industry or other private organizations.

REPORT OF PROGRESS FOR USDA AND COOPERATIVE PROGRAMS

A. Mechanisms of reactions of importance in salt-affected soils and waters and diagnostic techniques

At the U. S. Salinity Laboratory, Riverside, California, it was found that the migration of ions from soils to plants is characterized by three distinct stages. First, the ions dissociate from the adsorptive surfaces of the soil and enter the soil solution. This process, triggered by the general movement of ions in the direction of plant roots, is to restore or maintain ionic equilibrium between soil surfaces and their aqueous surroundings. The second stage consists of a translocation of the now more or less soluble ions towards the root surface. In association with the movement of water, this translocation is predominantly characterized either by mass flow, or by diffusion. Diffusion will prevail if the aqueous phase becomes increasingly constrained by electric field forces extending from root and soil surfaces. This is generally the case under arid conditions. The third stage consists of an exchange process involving root-produced hydrogen ions, followed by a translocation of the entering ions to inner areas of the cells. This process may be speeded up by water uptake, but is

never determined by it. Results of studies with red kidney beans indicate the occurrence of a preferential uptake or exclusion of ions relative to water characterizing the nutrition of plants. This suggests that crop management recommendations should be based on information which includes the diffusivity of the soil for water and ions under prevailing moisture conditions.

In inaugurating soil structure research at the U. S. Salinity Laboratory, it was found that one of the problems was the lack of methods for characterization and differentiation of the reactive surfaces of various soil constituents. Such information is essential to the study of clay-to-clay bonding, swelling, adsorption of organic materials on soil clay minerals, and reactions of amorphous cementing agents with the soil matrix. Preliminary results of studies to characterize such surfaces indicate pronounced differences in glycol retention by clay minerals saturated with different cations. Marked increases in the rate of desorption at higher temperatures suggest the possibility of a high temperature glycol desorption method allowing more rapid surface area measurements. Such studies appear promising in separating cation-glycol associations from mineral surface-glycol associations, so that even more importance may be assigned to surface area measurements made with ethylene glycol.

Research at the Laboratory has shown that the method for surface area measurements based upon the adsorption of o-phenanthroline and the Langmuir adsorption equation is not generally suitable for determining the surface areas of soils and clays because some clay minerals, notably halloysite and vermiculite, have interlayer surfaces that are not accessible to the relatively large o-phenanthroline molecule. The finding suggests, however, that measurements of surfaces accessible to the relatively large o-phenanthroline molecule and of those accessible to a relatively small molecule like ethylene glycol or water might provide useful information on such soil properties as swelling, dispersion, and permeability, especially as influenced by exchangeable sodium.

In biological reduction of sulfates at the Laboratory, it was found that under test conditions of submergence, with no drainage and no evaporation, sulfate reduction was limited by supplies of sulfate and organic matter. One to two units of undecomposed plant residue (straw or alfalfa) applied to two calcareous soils, a loam and a clay, reduced one unit of sulfate by weight. Study of five western soils which were similar except for native organic matter content indicated that soils containing less than 2 percent organic matter reduced insignificant amounts of sulfate over a 9-month period. In another test involving 12 representative western soils varying in organic matter content, pH, salinity, and exchangeable-sodium-percentage, sulfate reduction was small except in the high organic matter soil, indicating the paramount importance of the concentration of organic

energy material. As a consequence of sulfate reduction, there was a reduction in salinity and a change in the proportion of sodium to that of calcium plus magnesium in both the soluble and exchangeable forms, i.e., sodium-adsorption-ratio and exchangeable-sodium-percentage, respectively. Salinity reduction and increases in sodium-adsorption-ratio and exchangeable-sodium-percentage appear to be related to the amount of sulfate reduced. In addition, sulfate reduction rate appears to be related to texture, as a clay soil reduced sulfate twice as rapidly as did a loam soil.

In the greenhouse studies at the Laboratory to test the mathematical theories developed to describe the uptake of water by plants, those on the relation of transpiration to soil suction and water content gave results consistent with the theory. The data indicated that water movement to the plant roots governs the lower limit of water availability. It was also found that water can move upward appreciable distances through the soil before entering the root system. A method for integrating the soil suction over the entire root system was worked out and an approximate method of predicting water uptake patterns from a knowledge of the root distribution was derived. As a result, the water content can be predicted below which actual evapotranspiration will fall below potential evapotranspiration. If a relation between growth and the diffusion pressure deficit of the plant leaves can be established quantitatively, it should be possible to predict the relation between growth and soil suction.

Investigations at Norfolk, Virginia, have been directed toward solving brackish water problems of the Eastern Seaboard area. Lysimeter studies at Norfolk, Virginia, indicate that on soil treated with dilute sea water, calcium is leached out and sodium adsorbed by the soil. As a result, when most of the free salts have been leached out, the resultant soil solution is quite high in sodium as compared to other cations. Normal winter rainfall is usually adequate for leaching out salts accumulated during the growing season.

B. Physiological basis for tolerance of plants, and adaptation and response of plants to salt-affected soil and water

At the U. S. Salinity Laboratory, studies on the sensitivity of shrubs to specific ions, chloride and sodium, indicate a wide range in salt tolerance and pronounced differences in the response rate of different species. The rose has been most severely affected, defoliation and dieback resulting at even moderate salinity levels. It is the only species which was killed by all saline treatments in sand culture studies. Viburnum and guava, although more tolerant to salinity than the rose, also developed moderate to severe chloride injury symptoms. Pyracantha and Xylosma, on the other hand, were more sensitive to sodium. All plants of these two species died on the sodium sulfate treatment. Chloride injury symptoms have also appeared

on bottle brush (Callistemon) and Pittosporum, but these species have generally tolerated high levels of salinity quite well as have also Lantana and Oleander. Privet, Juniper, and arbor vitae appeared initially to be quite tolerant, but after surviving the summer they began to die during the autumn and early winter.

The effects of specific ions, such as chloride and sodium on growth of Indian Summer raspberry, Olallie blackberry, and boysenberry were investigated at the Laboratory in small sand tank cultures, employing final concentrations of 1 or 2 atmospheres of sodium chloride, calcium chloride, or sodium sulfate. The accumulation of toxic amounts of chloride and sodium in the leaves of all varieties was the principal cause for vine deterioration and, in this respect, chloride accumulated much more rapidly and caused injury much earlier in the season than sodium. Foliar injury symptoms first appeared as a marginal burn, followed by progressive necroses toward the base of the leaves. Indian Summer raspberry was extremely sensitive to chloride and sodium and the vines were killed, or nearly so, by all treatments except two, the control and one atmosphere of sodium sulfate. Olallie blackberry and boysenberry were much more resistant to chloride and sodium than the raspberry but the symptoms were, in general, similar to those described for raspberries. Evidence indicates that osmotic pressure was not nearly as critical in determining yield as was the accumulation of harmful levels of chloride early in the season. At higher temperatures, injury occurred at much lower levels of sodium and chloride than at low temperatures.

Sprinkler irrigation during the nonproductive strawberry season will reduce salt accumulation in the root zone, but it also permits foliar absorption of any toxic ions present in the irrigation water. Foliar accumulation of chloride by Lassen and Shasta strawberry varieties was compared under treatments in which chloride was absorbed either through the foliage or through the roots from solutions containing 10 milligram equivalents per liter of calcium chloride or sodium chloride. Shasta leaves accumulated three to five times as much chloride from root media as from corresponding foliar sprays, and Lassen leaves accumulated two to two and one-half times as much chloride from root media as from corresponding foliar sprays.

Knowledge of the magnitudes of forces binding water in plants is often necessary for studies on water movement in soil-plant systems and for studies on the effects of drought and salinity on plant growth. The diffusion pressure deficit of water in plant tissue and the osmotic pressure of the tissue sap increase markedly during the interval between full turgor and wilting in leaves. At the Laboratory, the thermocouple psychrometer was adapted to measurements of diffusion pressure deficit and osmotic pressure in excised leaves. Since one leaf of most plants is generally sufficient for analysis, this method is particularly well suited to experiments where only a limited number

of leaves are available. The results of studies to provide insight into the mechanism by which growth retardants increase the tolerance of soybeans to high fertilizer applications indicates that osmotic-pressure changes in the plant may favor an increased resistance to abrupt changes in the osmotic pressure of the medium but that tolerance to a continuing state of salinity is not increased thereby. In fact, growth reflects the depressive influence of both salinity and retardant. Study of the dynamic aspects of osmotic-pressure adjustment in plants confirms the importance of potassium in effecting short-term osmotic adjustments. Salinity stimulates the potassium increase during the day, but even during the first day of adjustment, other ions may begin to displace potassium in effecting a steady-state adjustment to salinity.

Studies on the growth and nucleic acid metabolism of leaves at the Laboratory have shown that salinity suppresses cell division. Also, that cell division is rate limiting in the growth (expansion) of both normal and salt-stunted leaves. Cell enlargement alone plays a small part in the process. The effects of salt and of a water stress are quite distinct, though they may be similar in their end result. Water stress clearly suppresses both cell enlargement and cell division. Salt also suppresses cell division but at the same time it tends to stimulate cell enlargement.

Progress has been made at the Laboratory in developing a boron tolerance list of plants, based quantitatively on the boron concentration of the saturation extract of the soil. Such a list would make it possible to select crops of proper boron tolerance based on the boron content of the soil. A technique has been developed whereby the boron concentration of a soil solution can be adjusted to a specified level and held at that level during the conduct of the plant-growth experiments.

At Norfolk, Virginia, supplemental irrigation with dilute sea water reduced yields of tomatoes, beans, potatoes, and onions only at high salt levels and the degree of reduction generally conformed to accepted salt tolerance values for these crops. There was enough residual salinity from these spring crops to affect the fall plantings of beans and peas. Alfalfa, fescue, and orchardgrass were more salt tolerant than the vegetable crops studied. Greenhouse studies indicate that the length of time the plant roots are exposed to a saline substrate may be a more critical factor than the salt sensitivity of any given plant growth stage. Other studies show that beans react differently to salinity at different soil fertility levels. Although bean pod yield reductions due to salinity are greater in terms of yield per acre at high fertility, there is little relative difference. Highly significant interactions between salinity and fertility were obtained for vine weights, leaf/stem ratios, moisture content of plant tissue, and nitrogen, calcium and potassium content of the plant material.

At Weslaco, Texas, chlorophyll content of young citrus leaves was significantly decreased by the effects of NaCl, $CaCl_2$, and Na_2SO_4 salts applied in irrigation water. This chlorophyll content reduction represents a subsequent reduction in synthesis of carbohydrates, proteins, and other substances required for normal plant growth and production.

C. Water composition and reactions occurring when salt-affected soils are irrigated and drained

Based on research at the U. S. Salinity Laboratory, it is now possible to anticipate the quantity of calcium that will precipitate or, conversely, the quantity that will remain in solution when salt-affected soils are irrigated by natural waters containing calcium and carbonate ions. These findings are important not only to agriculture but to all water users where scale formation is a problem.

Salt balance is defined as the relation between the quantity of dissolved salts carried to an area in the irrigation water and the quantity of dissolved salts removed by the drainage water. Leaching requirement is defined as the fraction of the water entering the soil that must pass through the root zone in order to prevent soil salinity from exceeding a specified value. The interrelationship between these two criteria and the methods for their calculation have been worked out and tested on data from the Rio Grande salt-balance investigations by the Laboratory. It concluded that salt balance is a reliable and useful criterion for indicating year-to-year trends in salinity conditions on irrigation projects. Similarly, leaching requirement is a reliable and useful criterion for anticipating the leaching that would be necessary to prevent the salinity in the soil from exceeding a specified level. The clarification of the relation between these two values and the confirmation of their utility are of importance in irrigation management.

At Weslaco, Texas, samples of rainwater caught periodically at stations throughout the Lower Rio Grande Valley contained significant quantities of salts. These salts are a partial source of saline accumulations in Valley soils. Approximately 120 pounds of salt per acre are added by rainfall to coastline soils each year. The salt content of rainwater, however, decreases with land distance from the coastline. At a point 50 miles inland it was approximately one-half that at the coastline.

D. Crop and soil management systems for various levels of salinity and sodium saturation of soils

Results from studies on Sebree-Chilcott soils in southwestern Idaho continue to show that these saline-sodic "slick spot" soils can be effectively reclaimed by several methods. In small plot studies,

profile mixing (simulated deep plowing) to several depths without gypsum, profile mixing and subsoiling with addition of gypsum, and gypsum only at rates of 20 tons per acre, greatly improved water intake and crop growth. Salinity and exchangeable sodium content of the soil was reduced to low, noncritical levels within 1 to 2 cropping years.

Experiments on deep plowing and subsoiling of large field plots and farm fields indicate that the soil can be effectively and economically reclaimed by the deep plowing treatments alone. Infiltration rates and penetration of water and roots was greatly improved. Salinity and exchangeable sodium content were reduced to noncritical levels within 2 crop years. Crop production on the deep-plowed Sebree (slick spot) soils was greatly increased; yields of alfalfa hay, barley, wheat, sugar beets, and corn were increased four to five times in comparison to the yields on the unplowed soils.

Studies on the stratified, high-silt Malheur soils in southeastern Oregon indicate that deep plowing may be useful on these soils. Crop yields were greatly increased the first year after plowing. Water infiltration and water and root penetration were greatly increased. Preliminary data on the change in the salinity and exchangeable sodium content indicate that the salts and exchangeable sodium were markedly reduced within 2 crop years.

At Weslaco, Texas, cotton burs applied as a heavy residue cover to a highly saline soil surface facilitated the removal of salts from the surface 42 inches in a period of 8 months. Much of the removal occurred in the first 5 months. Resulting salt concentrations were below levels known to adversely affect plant growth. Salt removal was also facilitated, but to a lesser degree, by establishing a permanent ridge-furrow surface management system.

E. Reclamation by leaching

Infiltration studies at Huntley, Montana, on a slowly permeable saline-alkali soil show the importance of high electrolyte content of the leaching water in hastening the leaching process. With high-quality river water (EC = 0.02 mmhos/cm) the infiltration rate was only 0.2 inch per day. With water of high conductivity (40 mmhos/cm), initially obtained by adding $CaCl_2$ and progressively reducing the conductivity of the added water to one-half each 14 days, the infiltration rate was 2.6 inches per day for the first 22 days and 2.3 inches for 55 days. With a single application of high $CaCl_2$ water, followed by river water, the infiltration rate was 1.9 inches per day for 22 days. These results corroborate findings of the U. S. Salinity Laboratory.

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Reclamation by Leaching

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AREA 8 WATER AND WIND EROSION CONTROL PRINCIPLES, PRACTICES, SYSTEMS, AND PREDICTION METHODS FOR CONSERVATION OF CROP AND RANGELANDS

Problem. Water and wind erosion control continues to be a problem in both humid and semiarid areas where periodic plowing, tilling, and planting operations are a part of the farming system. Wind erosion is a serious problem in many irrigated and dryland farming areas. Careless irrigation techniques result in erosion from irrigation water application. Erosion and runoff control measures need constant improvement for compatibility with new farming systems. Sheet, rill, and gully erosion from farm fields in humid and semiarid areas are the major sources of silt that pollutes the streams of these areas.

The wide variations possible under factors of soil, climate, crops, and management create highly complex relationships and make it imperative to determine basic principles governing movement of soil and water under the forces of nature. From these principles improved control measures may be designed and prediction equations developed that will provide a scientific basis for application of control practices and structures to farmland and for land use decision making in successful water resource planning, in watershed protection and development programs, and in selection of critical areas to be retired to recreational or other safe use.

USDA PROGRAM

The Department has a continuing long-term program in water and wind erosion involving soil physicists, soil scientists, and agricultural engineers who are engaged in basic research for the development of new knowledge and in the application of known principles to solution of farm erosion control problems. Basic principles and mechanics of water erosion are under study in Indiana, Minnesota, Iowa, Illinois, New Hampshire, Maine, and New York and of wind erosion in Kansas. Interrelations of climate, soil, topography, cover, and management to runoff and soil movement for water erosion control are studied in New York, Maine, Mississippi, Georgia, Minnesota, Iowa, South Dakota, Wisconsin, Indiana, Missouri, Nebraska, Kansas, Texas, Oklahoma, Washington, and Oregon; and for wind erosion control in Kansas, Texas, and Idaho. Studies for the development and improvement of prediction methods for water erosion are underway at Lafayette, Indiana, and for wind erosion at Manhattan, Kansas. The development of practices, structures, and systems for modification of wind, water, and soil movement is underway in New Hampshire, New York, Virginia, Georgia, Wisconsin, Iowa, Minnesota, Missouri, Kansas, Oklahoma, and Texas.

The Federal scientific and engineering effort directed to research and development in this area totals 39.1 professional man-years. Of this number, 7.5 are devoted to basic principles and mechanics of water and wind erosion; 21.9 to interrelations of climate, soil, topography, cover, and management to runoff and soil movement; 1.9 to equations for predicting soil and water losses; and 7.8 to practices, structures, and systems for modification or control of wind, water, and soil movement.

RELATED PROGRAMS OF STATE EXPERIMENT STATIONS AND INDUSTRY

The State Experiment Stations in 1961 had a research program in erosion control equivalent to 12.3 professional man-years divided as follows: Basic principles and mechanics of water and wind erosion for development of a better understanding of forces involved in rainfall and wind movement and in determination of soil physical and chemical properties related to erosion, 4.7; interrelations of climate, soil, topography, cover and management to runoff, soil movement, and loss, 3.2; and practices, structures, and systems for modification or control of wind, water, and soil movement concerned primarily with terracing, strip cropping, farming systems, and the reclamation of eroded soils, 4.4. Much of this work is planned and conducted in cooperation with the U. S. Department of Agriculture.

Available information indicates current research in this area by industry or other nonpublic organizations is limited to development of soil stabilants and matting materials for erosion control in special situations, frequently of a nonfarm nature. Probably not more than 5 professional man-years are engaged in this activity.

REPORT OF PROGRESS FOR USDA AND COOPERATIVE PROGRAMS

A. Basic principles and mechanics of water and wind erosion

Water Erosion. Progress in this area during the past year has been largely in the area of instrumentation, assembly of equipment, and some preliminary results. In New Hampshire, equipment was developed and used for measurement of the impact forces of various size waterdrops. Using this equipment it was shown that for a given stress produced by individual drops from 3 to 6 mm in diameter but not at terminal velocity, the transmitted strain increased with increased thickness of water film to a maximum and then decreased as thickness of film further increased. In studies in Minnesota, drops striking a dry paper surface did not produce splash unless the angle of inclination of the target surface was greater than 40°. Splash from a 0.25-mm film of water over glass moved from the target area at about 40° from the horizontal, but when the film increased to 2.5-mm depth the direction of splash was essentially vertical.

In Indiana, preparation of a laboratory plot surface for mechanics of water erosion studies required the accurate separation of glass beads by size in the 100- to 1,000-micron range. A wind method of separation was developed which proved preferable to either sieving or elutriation. The beads are introduced at the front of a separator through which a continuous uniform flow of air is passing. The different size beads are collected in successive compartments along the bottom of the separator. Beads from compartments that do not give sufficient separation are again introduced. Beads of different shapes or densities and foreign materials are also separated.

In Iowa, identification and evaluation of soil properties affecting the erodibility of soils was begun both in laboratory and under reproducible artificial rainstorms on field plots. The similarity of infiltration-time curves secured in the laboratory and on the same soil type in the field indicated that the infiltration-time curves for a particular soil may be the result of surface phenomena which can be duplicated in the laboratory. This soil property appears to be closely associated with erodibility. Measurements at 4-percent slope under a laboratory rainfall simulator showed the order of decreasing erodibility of five Iowa soils to be: Marshall, Grundy, Carrington, Seymour, and Ida. In Indiana, studies using a field plot rainfall simulator on identically cultivated small field plots with similar cropping histories showed that the physical measurement, suspension percentage, correlated more closely with erosion losses than did mechanical analysis, clay ratio or dispersion ratio. These studies of soil properties that influence the magnitude of the soil erodibility factor K in the universal erosion equation will be continued.

Wind Erosion. Preliminary results of wind gustiness studies in Kansas indicate a normal distribution of gustiness factors at the 40-foot height but significant kurtosis or skewness occurring at the 1-foot height under both neutral and strong inversion atmospheric stability conditions. Other studies in progress deal with the effect of surface roughness such as soil clod, ridges, and other disfiguration on drag velocity, drag and erodibility of the soil by wind.

B. Interrelations of climate, soil, topography, cover, and management to runoff and soil movement

Water Runoff and Erosion. A comparison of runoff and erosion under three different methods of seedbed preparation on three different slopes in New York indicated that soil losses from the plow-plant type of minimum tillage for corn were approximately one-fourth of those from corn grown on conventionally tilled land. This was most pronounced on the 17-percent slope while soil losses on the 9-percent and 5-percent slopes were relatively low regardless of seedbed preparation. Losses were greater from snow melt during early spring thaw than from rains occurring during the growing season.

In the Corn Belt, minimum tillage for corn has effectively increased infiltration and decreased erosion. From studies using a field plot rainfall simulator in Indiana, soil losses from the third successive year of corn were essentially double those from the first-year corn for both conventional and minimum tillage. However, the relative effectiveness of the minimum-tillage was only very slightly less in the third year of corn than in the first year after sod.

Tests in both Indiana and Wisconsin showed that the potential benefits of minimum-tillage practices may be lost as a result of soil crusting by intense rainfall early in the growing season. When surface crusting was eliminated by cultivation, minimum-tillage reduced soil loss about 40 percent, even when corn was mature. Four or five months after planting, the minimum-tilled plots were still much less compacted than the conventionally treated check plots. During the critical first two months after corn planting, Wisconsin studies showed minimum-tillage methods were most effective when plowing and planting were on the contour. Wheeltrack planting on the contour on Fayette silt loam with 16-percent slope lost 0.33 inch in runoff and 0.8 ton soil per acre from natural rainfall, compared with 0.86 inch in runoff and 5.8 tons of soil from adjacent "conventionally" planted corn, also on the contour.

A surface mulch of chopped hay superimposed upon the plow-plant method greatly reduced runoff and almost eliminated soil loss from Russell silt loam, a well-drained soil in Indiana, during two test periods in each of which 5 inches of simulated rain was applied at 2-1/2 inches per hour. About one-half ton of soil was lost from this treatment as compared with 13 tons from a similar minimum-tillage treatment with no mulch. Orchardgrass and alfalfa hay harvested from adjoining strips equal in area to the corn plots were chopped and blown over the corn plots after first cultivation. These preliminary results indicate that this treatment may be very effective in controlling erosion on short irregular slopes where contour-type conservation practices are not feasible. The plow-plant method would control erosion during the early weeks after planting, the single cultivation would destroy crusts produced by early rainfall, and the mulch would prevent sealing and ready transport of soil by subsequent rainfall without the adverse effects of mulch on soil temperatures in the early spring.

Residue management to retain large quantities of prior-crop residues at or near the surface very effectively reduced runoff and erosion from both corn and small grain in tests in five Corn Belts states. During the past 8 years, corn following corn with chopped corn stover mulch and added barnyard manure averaged 80 percent less runoff and 93 percent less soil loss than a corn-oats-meadow rotation without the mulch and manure on Fayette silt loam with 16-percent slope. Comparable results were obtained from a 7-year similar study

on Dodge silt loam with 8-percent slope. In an 8-year test on the Midwest claypans, erosion from continuous corn at very high fertility was further reduced about one-third by leaving a mulch of shredded corn stalks on or near the surface. Using a field cultivator instead of a moldboard plow to prepare the seedbed reduced erosion from first-year corn after meadow from 5.9 tons per acre to 1.8 tons at LaCrosse, Wisconsin, and reduced soil loss from oats from 12 tons to 5 tons.

At Cherokee, Oklahoma, runoff from small rings placed in field plots was correlated with the plot runoff. The relation was curvilinear and much closer for major runoff-producing storms in which the entire plot area contributed to runoff. Infiltration rates were similar on lovegrass and alfalfa plots. Initial rates were high on wheat plots because of loose surface soil from seedbed preparation. Soil concentration in runoff water was increased 6 times by removing wheat stubble surface residue and 12 times by removing lovegrass top growth with very little influence on infiltration.

On the basis of 1960 and 1961 results at Pendleton, Oregon, vertical mulching is not a recommended practice in the Columbia Basin of Oregon. The mulched trenches reduced runoff and erosion only when they were open to the surface. Tillage and seeding operations after vertical mulching tended to seal the surface with loose soil and essentially eliminated any beneficial effect of the trenching. At harvest time, strips 12 to 20 inches wide over the trenches were bare of wheat. Work near Rockford, Washington, showed that vertical mulching had no appreciable effect on the growth of alfalfa.

Runoff and soil loss data at Watkinsville, Georgia, show there is little hazard from erosion on moderately sloping land, even under very severe rainfall conditions when row crops follow sod crops on contour-farmed land. Rainfall in 1961, totaling over 62 inches was 33 percent above normal and the rainfall erosion index was 200 percent of the 22-year average. Soil loss from a 3-year rotation of fescue, fescue and corn; a 4-year rotation of fescue, fescue, corn and cotton; and continuous cotton was in the ratio 1 to 7 to 47, respectively, and runoff was in the ratio 1 to 3 to 8. These findings strongly indicate that sod-based rotations are essential for production of row crops on sloping Piedmont land if conservation of rainfall and soil are to be attained practically.

Wind Erosion. In studies of materials for controlling erosion while vegetation was becoming established at Manhattan, Kansas, properly anchored vegetative mulches far exceeded, from the standpoint of cost and effectiveness, new materials that are claimed to be effective in controlling wind and water erosion. At quantities sufficient to control erosion, the total cost was $89 to $150 for hauled-in and anchored wheat straw mulch, $247 per acre for cutback asphalt, $335 per acre for asphalt-in-water emulsion, and about $1,000 per acre for latex-in-water emulsion. Wood cellulose fiber was effective in

controlling wind erosion at a cost of $95 per acre, but was ineffective in controlling water erosion. Resin-in-water emulsion was effective in controlling wind erosion of sandy soil at a cost of $213 per acre, but was ineffective in controlling wind or water erosion on fine-textured soil. The vegetative mulch was the only material capable of appreciably reducing runoff. Of the five types of packers tested for anchoring vegetative mulches, the rolling disk packer was by far the most effective.

In a study of tillage implements to keep crop residues on top of the soil at Alliance, Nebraska, and Colby, Kansas, the most effective were the 3- and 7-foot sweeps, followed by the rodweeder equipped with small sweeps, the one-way disk, and the chisel point cultivator in order of decreasing effectiveness. But, the sweep implements sometimes were not fully effective in killing weeds and in bringing wind-resistant clods to the surface. From this study, new knowledge was gained to help the farmer select the type of implement to use under specific soil moisture, crop residue, and climatic conditions.

At St. Anthony, Idaho, use of a skew treader following sweep plowing resulted in increased soil erodibility by wind. Erodibility of a rodweeded field was increased from zero to 0.45 ton per acre by running the skew treader over the land twice. Skew treading once during the fallow season and then rodweeding for the remainder of the season caused a 33-percent reduction in residue and an average erodibility of 0.80 ton. Double skew treading at each of three weeding operations caused a 60-percent reduction in residue and a total wind erodibility of 0.45 ton of soil per acre.

C. Equations for predicting soil and water losses

Water Runoff and Erosion. Development and general adaptation of the universal rainfall erosion prediction equation to the 37-state area east of the Rocky Mountains was completed during the past year. With the aid of Soil Conservation Service personnel in numerous states, the new procedure was widely tested against the knowledge and observations of experienced specialists in the field of soil and water conservation. The validity of the equation in all localities where individual factors had been evaluated was consistently supported by these tests. In the High Plains, in particular, much remains to be done in development of cropping-management and soil erodibility factors, and of soil loss tolerance values. Studies to provide this knowledge were started in Nebraska, Kansas, and Texas during the year. Studies of soil erodibility were started in Iowa, Indiana, Maine, and Georgia.

Maps showing the rainfall-factor value for every locality in the 37 states east of the Rocky Mountains were completed in 1961 and distributed to SCS operations personnel. Iso-erodents (lines joining points with equally-erosive rainfall) were plotted with reference to county lines and other easily identified reference points.

Erosion-index distribution curves for 34 geographic areas needed to predict the effects of rainstorm distribution on cropping and conservation practices were completed and distributed for field use. Each curve is applicable only within a geographic area within which the seasonal distribution of erosive rainstorms is approximately homogeneous.

With the 1961 additions, runoff and soil loss data have been assembled at Lafayette, Indiana, from 47 research stations in 24 states and Puerto Rico for use in development and improvement of the prediction equation. Study of this data has indicated that conservation measures which minimize soil loss from the 1-year and 2-year storms can greatly reduce average annual soil loss even though they do not provide complete control against the extremely severe storms. Of 11,290 tons of soil lost in 315 location-years of row crops, about one-third was lost from storms with a return period of less than 1 year, about one-third from storms with return periods of from 1 to 2 years, and about one-third from the larger storms. This relationship was essentially the same regardless of whether the erosion index, amount of rain, maximum 15-minute intensity or maximum 30-minute intensity was used as the basis for storm-size classification.

In individual-storm runoff analyses of data from continuous corn, rotation corn and continuous fallow assembled at Layayette, Indiana, the best overall estimator of runoff amount was rainfall energy. As an average of six studies, energy explained 78 percent of the total runoff variance, while rain amount explained 70 percent, maximum 30-minute intensity explained 43 percent, and maximum 15-minute intensity explained only 31 percent. Other variables which provided some measure of the interactions of rainfall intensities with storm amount were also better indicators of runoff than were rain amount or 30-minute intensity alone. In six individual-plot analyses, from 85 to 98 percent of the runoff variance was accounted for by 19 variables in multiple regression equations.

Wind Erosion. An important milestone in research progress on wind erosion was reached in 1961 with the completion of development of a practical wind erosion equation which, when applied to any field anywhere, will tell whether or not the field is sufficiently protected from wind erosion. Moreover, the equation can be used as a tool to estimate what field conditions a farmer should establish to reduce wind erosion to an insignificant amount. The equation is based on research data accumulated during many years from measurements in wind tunnels and in the field. Its usefulness lies in its simplicity. First, the condition of each of the five major factors that influence wind erosion is determined for the field by simple specified procedure. These 5 factors are: Percent of nonerodible soil fractions determined by standard dry sieving; local wind erosion climatic factor; soil surface roughness; equivalent width of field; and the equivalent

quantity of vegetative cover. Then, the potential amount of wind erosion of the field is read almost at sight by using accompanying charts and tables. The equation is a potent new tool which is expected to aid technicians and agricultural leaders in their soil conservation and education work.

Development of the wind erosion climatic factor for use in the wind erosion equation has been completed for different locations in the United States and the agricultural areas of Canada. This factor was derived from known relations between soil moisture, wind velocity, and quantity of soil erosion by wind. The potential annual soil loss as would occur at Garden City, Kansas, for some particular set of field conditions multiplied by the wind erosion climatic factor for any geographic location will give the potential soil loss for that particular set of field conditions at that location. The procedure can be used in reverse to determine field conditions necessary to reduce wind erosion to any degree at any geographic location.

D. Practices, structures, and systems for modification of wind, water, and soil movement

Water Runoff and Erosion. Contouring provided adequate erosion control for continuous corn grown on long, gentle slopes (420 ft.) of slowly permeable Mexico soil in Missouri during 6 of the past 8 years. However, extremely high soil losses in 1957 and 1961 brought the 8-year average annual loss to 4.3 tons per acre, or about 50 percent greater than the accepted maximum for this soil. The loss in 1961 was nearly 19 tons per acre. These data indicate that local rainfall pattern and soil permeability as well as steepness of slope must be considered when determining maximum field lengths for contoured row crops.

In a contour farming study at Marcellus, New York, begun in 1942, yield benefits of the practice increased significantly during the first two-thirds of the period. Since that time the established level of increase has been maintained on the average, although benefits have fluctuated widely from year to year. Contour benefits for beans during the later period varied the least, ranging from 13 to 30 percent with a mean of 20 percent. With wheat, the range was from 1 to 70 percent with a mean of 25 percent. Corn was the only crop not showing a contour benefit each year. Yield changes ranged from -8 to +36 percent with an average of 10 percent.

Increased mechanization in farming has magnified the problem of short point rows when contour farming is practiced on rough, sloping topography. In order to eliminate this problem, land forming on sloping land in conjunction with contour operations in Virginia is being studied as part of a management program for tobacco.

Field studies in Georgia for establishing parallel terrace systems and grassed waterways showed that the following five chronological steps are necessary: (1) Smoothing down of old terraces on the field; (2) general cutting and filling to smooth out ditches and irregularities of land configuration; (3) layout and construction of parallel terraces; (4) construction of waterways; and (5) final grading parallel to terraces. Limited experience with farm-owned equipment in 1961 showed the construction cost to be $2.41 per 100 feet of new terrace or $9.00 per acre, and $2.75 per 100 feet of waterway or 12.4 cents per cubic yard of earth moved, for a total cost of $10.13 per acre. Total earth moved was small, equalling only 57 cubic yards per acre. Tractor time, including all operations, equalled 3.32 hours per acre. Operators time was computed at $1.00 per hour.

In Iowa, soil and water losses from 72-foot terrace intervals have been greater (per unit area) than losses from 125-foot terrace intervals on Ida silt loam. In construction of these large, closed-end level terraces, the soil from the channel area is pushed down the slope to the terrace ridge. This action results in an increased land slope between terraces. As the interval between terraces decreases, the land slope increases. This undoubtedly accounts for the larger soil and water losses per unit area on the narrower-spaced terraces. The slope gradient between the 72-foot spaced terraces is now 16.8 percent, and between the 125-foot spaced terraces, 14.4 percent. The soil loss ratio estimated from the soil loss prediction equation is practically the same for a 14.4-percent slope 125 feet long as for a 16.8-percent slope 72 feet long.

Preliminary results from Chickasha, Oklahoma, indicate that several grasses have sufficient flood-water inundation tolerance to withstand the normal expected duration and depth of flooding that occur during early spring. The ability of an individual grass to withstand flooding was affected by the interactions of depth, stage of growth, and duration of flooding. Grasses showing most promise are bermudagrass, some switchgrass selections, buffalograss, vine-mesquite, and prairie cordgrass. Grasses showing poor flooding tolerance include King Ranch bluestem, big bluestem, El Kan bluestem, weeping lovegrass, alkali sacation, and eastern gamagrass.

A study of gully development in New England river terraces or alluvial plains and plateaus has indicated that formation occurs for the most part during the very short period of spring thaw. Since this is so intimately related to the phenomena of freezing and thawing and related factors, this study will be extended to evaluate these factors as they affect surface and subsurface water movements. Recent investigations indicate that seepage flow may contribute to gully development in some soil formations. Diking systems were found to be the most effective means of control when they are built along the scarp of a terrace and follow the outline of any previously formed gully.

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AREA 9 MOISTURE CONSERVATION FOR THE EFFICIENT AND EFFECTIVE USE OF PRECIPITATION ON CROP AND RANGE LANDS

Problem. In most parts of this country the major problem that plagues agriculture is recurring drouth. Every year emergency areas develop as a result of prolonged drouth. These emergencies represent a large dollar loss to the public. Agricultural use of precipitation is very inefficient. The fallowing system used in the Midwest to increase the soil moisture supply only stores 1 inch out of every 5 that falls. In the humid region, evaporation losses from the soil surface under row crops may account for 50 percent of the precipitation that falls on the land. Fundamental information is needed on the basic mechanisms involved in the loss of water by evaporation from soils under different climatic, land use, and cover conditions. The problem of inefficient moisture storage and utilization is even greater on rangeland than on cropland. With rangeland there is an extreme paucity of soil and moisture research data. Improved land-forming techniques should be studied, as they may alter the utilization of precipitation on range and cultivated land. The influence of tillage methods and residue management practices on the use of precipitation on cultivated land should be evaluated.

USDA PROGRAM

The Department has a continuing long-term program involving physicists, engineers and soil scientists engaged in both basic studies and the application of known principles to the solution of the moisture conservation problems. Research evaluating basic relationships between climatic factors and loss of water by evaporation is being done at Fort Collins, Colorado, Manhattan, Kansas, Bushland and Temple, Texas, La Crosse, Wisconsin, Riverside, California, and Mandan, North Dakota. Physical factors associated with increasing infiltration are being studied at Mandan, North Dakota, Akron, Colorado, Manhattan, Kansas, and Bushland and Temple, Texas. Methods for reducing evapotranspiration are studied at Akron, Colorado, Bushland, Big Spring, and Weslaco, Texas, and Fort Collins, Colorado. At all locations the work is done cooperatively with the respective State Experiment Stations.

The Federal scientific effort devoted to research in these areas totals 23.3 man-years. Of this number, 6.6 are devoted to factors affecting infiltration; 6.5 to basic relationships between climatic factors and loss of water by evaporation; and 10.2 to methods of reducing evapotranspiration.

RELATED PROGRAMS OF STATE EXPERIMENT STATIONS AND INDUSTRY

State Experiment Stations in 1961 reported a total of 27.8 professional man-years divided as follows: Factors affecting infiltration, 17.2;

basic relationships between climatic factors and loss of water by evaporation, 7.9; and methods of reducing evapotranspiration, 2.7. Research on the effects of soil management practices and soil types on infiltration rates are being conducted cooperatively among the Alaskan Indians, Iowa, Kansas, Michigan, and Nebraska stations. Practical methods for determining and predicting relative infiltration rates of soils during irrigation and rain are being developed. Also included are studies to relate climatic factors to loss of water by evaporation and transpiration.

Industry and other organizations. To our knowledge no research work is being done by industry or other organizations in this area.

REPORT OF PROGRESS FOR USDA AND COOPERATIVE PROGRAMS

A. Factors influencing moisture storage

Cover. Because stored soil moisture must be relied upon to produce a normal corn crop at Morris, Minnesota, considerable effort has gone into the development of management practices that will increase the amount of water stored from precipitation during the fall and winter. Measurements made in 1961 showed that 22, 43, or 52 percent of the precipitation was stored during the fall and winter if the soil had been fall-plowed, if alfalfa was left standing, or if the soil cover was cornstalks, respectively.

Freezing and Thawing. In laboratory studies at Mandan, North Dakota, to determine soil moisture movement during freezing, little if any redistribution of water in a soil column was found when the column was frozen. Ice-covered soil surfaces lost four times as much water as a frozen soil surface and six times as much water as a frozen soil covered with 1 inch of dry mulch.

Landforming. Continued emphasis was placed on landforming and other mechanical means of conserving moisture at Mandan, North Dakota. On a bench terrace experiment, little runoff from the contributing area onto the bench terrace took place during the drouth year of 1961. Wheat yields averaged 17.0, 13.3, 7.2, and 3.2 bushels per acre for fallow with no contributing area, continuous wheat with a waterproofed contributing area, continuous wheat with a grass contributing area, and continuous wheat, respectively. Fallow treatments had an unusually good moisture supply at seeding time owing to an optimum previous season. On a field-scale study at Mandan, corn yields averaged 14.1, 8.9, and 2.1 bushels per acre on level benches with contributing areas, level benches without the contributing area, and on the contributing area, respectively.

At Akron, Colorado, conservation-bench terraces stored 1.6 to 3.0 inches of available water, which was 23 to 43 percent of the precipitation. Leveled and diked areas, formed to use runoff from other areas, stored from 2.3 to 4.6 inches of water. Snow trapping studies at Akron showed that double sorghum rows properly spaced accumulated from 1.2 to 1.5 inches of water from the 3.77 inches of precipitation that fell as snow. Corn proved relatively unadapted as a barrier material for the conditions at Akron.

Infiltration. Water intake rates were measured in North Dakota rangelands on sites that had been heavily, moderately, and not grazed. During one-hour tests, average intake rates were 1.48, 2.15, and 4.27 inches per hour for the heavy, moderate, and non-grazed plots. Eighty-eight percent of the variation in intake rates was associated with amount of standing herbage and the mulch material on the plots. In Arizona, plots with good cover (6,570 pounds per acre) had intake rates three times those of plots with sparse cover (317 pounds per acre) during the first 30 minutes of testing. During the second 30-minute period the plot with good cover took in nine times more water than the plot with poor cover.

At Weslaco, Texas, a numerical method has been developed for estimating the influence of a less permeable horizon on the infiltration in a profile. Computations made on a relatively impervious Geary silt loam overlying a pervious Sarpy loam indicated that a layer of the impervious soil as thin as one-half centimeter decreased the infiltration of the Sarpy loam considerably. When the thickness of the impervious lens was 5½ centimeters or more, infiltration was the same as if the entire profile were Geary silt loam.

Chemical Fallow. At Sidney, Montana, chemical fallow has not been as successful as tilled fallow in conserving moisture. This was due largely to incomplete control of wild oats by the chemical. At the Pendleton and Sherman stations in the Columbia Basin of Oregon, chemical fallow (1.6 pounds atrazine plus 1.0 pound amitrole per acre) did not have a significant effect on moisture conservation, nitrate production, or on the population of soil micro-organisms. There was, however, a decrease in grain yield due to the chemical treatment at the Pendleton location (23.1 compared to 29.7 bushels per acre). This depression in yield was not noted at the Sherman location nor at Pendleton on the chemical treatments that were tilled.

Tillage. At Bushland, Texas, three years' results indicate that deep plowing and vertical mulching Pullman clay loam did increase the water intake rates but did not affect yields. Measurements made over the 3-year period show the effectiveness of the treatment did not decline with time. Forage sorghum residue used for the vertical mulch could still be identified after three years.

Summer fallow tillage experiments for moisture conservation in the dryland winter wheat area of eastern Idaho show that delaying plowing reduces moisture storage at seeding time. When plowing was done early with the soil at field capacity, the available moisture at seeding time was 13.9 percent as compared with 9 percent for the treatment that was tilled when the top 6 inches had lost all available moisture. The treatment tilled when the top 6 inches had lost one-half available moisture had 10.7 percent moisture at planting time.

In comparing annual cropping with summer fallow for spring wheat at St. Anthony, Idaho, it was found that fall chiseling permitted storage of 72 percent of the winter precipitation as compared to 41 percent on the treatments not chiseled. Eighty-six percent of the deviation in yield was accounted for by the amount of stored moisture at the start of the growing season, with each inch of stored moisture producing 2.12 bushels of wheat.

B. Factors Affecting the Loss of Water by Evaporation

Salts. The influence of small amounts of salts in the soil profile on water movement and evaporation was studied in soil columns in laboratories at Fort Collins, Colorado. Salt concentration gradients formed at the soil surface in all treatments. Such gradients were shown to be a major force in the movement of water in soils at moisture contents less than one-half of field capacity. Salt concentrations at the soil surface were associated with higher moisture contents and consequent increased evaporation.

Viscosity of Water. The viscosity of water adjacent to soil particles was measured as a function of distance of the water from the particles. The first layer had a viscosity three times that of water, but the viscosity of successive layers rapidly approached that of bulk water. This information collected at Fort Collins, Colorado, is necessary for an understanding of movement of water to the evaporating surface in soils.

Plastic Covers. Corn grown on plots covered with white plastic at Fort Collins, Colorado, yielded 16 percent more than corn grown on plots with no cover and 5 percent more than corn grown on plots with a black cover. Water was not a limiting factor in this experiment. Sensible heat from the soil surface to the air, calculated from air temperature gradients, was increased 130 percent by covering the soil with black waterproofing and decreased 44 percent by covering the soil with white waterproofing. These data indicate that energy not used to evaporate water in the soil can be reflected if the waterproofing material is light in color. In an evaporation study using lysimeters at La Crosse, Wisconsin, water use by corn on covered plots was 49 percent of that for the corn grown on the uncovered lysimeter.

At Manhattan, Kansas, a two-dimensional electric simulator was used on an evaporation problem. In this simulated study, one-fifth, two-fifths, three-fifths, and the total soil surface was exposed to evaporation. The maximum difference among the treatments was found at the end of the run at which the cumulative evaporation from the one-fifth, two-fifths, and three-fifths exposed treatments was 85, 94, and 96 percent of the total exposed treatment, respectively.

Evaporation Suppressing Materials. Exploratory laboratory research at Bushland, Texas, on the use of monohydric aliphatic alcohol to retard evaporation from the Pullman clay loam soils indicates that these materials may be effective in reducing evaporation from the soil surface over short periods of time, but in all probability would have no effect on the reduction of total evaporation. There were also indications that they may lower the water infiltration rate.

Soil Texture. At Riverside, California, moisture losses by evaporation over a 12-week dry summer period were 3.2, 4.6, and 3.8 inches for a Hanford loamy sand, sandy loam, and very fine sandy loam, respectively. During the same period an Arlington sandy loam and an unclassified clay loam lost 2.3 and 1.4 inches, respectively. The depth of moisture loss ranged from 18 inches in the clay loam profile to over 5 feet in the Hanford loamy sand and sandy loam. Evaporation moisture losses were greater for soils with medium texture than for soils with either coarse or fine texture.

Shrinkage Cracks. Periodic measurements of shrinkage cracks in Houston black clay at Temple, Texas, confirmed previous observations that the earliest and largest cracks developed between crop rows and that the rate of crack growth was much greater with growing crops than with fallow. The average surface area exposed with cracked soil was 3.6 times that of normal soil.

C. Factors influencing the use of moisture by the crop

Crop Varieties. Water use efficiency of several varieties of forage sorghums and Sudangrass were evaluated at Akron, Colorado, under heavier than normal rainfall. Water use efficiencies varied considerably among varieties within a species. This work points out the possibility of selecting varieties on the basis of water use efficiency.

Cropping Systems. At Bushland, Texas, wheat on fallow appeared to be able to extract moisture from the fifth and sixth feet of soil more effectively than did continuous wheat. This may have been due to more extensive rooting systems in the fallowed wheat.

At Big Spring, Texas, cotton planted in skipped row systems, such as two rows planted and one row skipped, or two rows planted and two rows skipped, gave higher row-acre yields but made no difference on a comparable acre basis than did the standard row spacing. Results from a 4-year study showed that dryland cotton on Amarillo fine sandy loam seldom used all of the available moisture in the fallow portion of a four-cotton row, four-fallow row system. Cotton used all or nearly all of the soil moisture in a two-cotton row, two-fallow row system. All moisture was extracted in a two-cotton row, one-fallow row system, or a one-cotton to one-fallow row system.

In other studies at Big Spring, Texas, soil moisture data obtained with cotton and grass in rows indicate that cotton utilizes moisture as effectively as native perennial grass, but with cotton the rapid moisture use is delayed until the heavy fruiting period. Some of the shorter native grasses use little moisture to a distance greater than 60 inches but taller grasses such as Blue Panic may utilize moisture to a distance of 80 or more inches from the planted row.

Water Table. At Weslaco, Texas, in an area where the water table declined from 40 inches at seeding time to 72 inches at plant maturity, soil moisture measurements taken at various growth stages of grain sorghum indicated that a substantial portion of the moisture used by the crop came from the water table.

Fertilizer. Studies to determine the best combination of corn population, fertilizer, and other management practices for efficient moisture use in western Minnesota, eastern South Dakota, and eastern North Dakota showed that corn population, nitrogen additions and phosphorus additions increased the water use efficiency values.

At Akron, Colorado, moisture studies with grain sorghum have shown that approximately 9 inches of water (growing season rainfall plus moisture stored in the soil at planting time) are necessary for a bushel of grain to be produced. Average growing season rainfall (June-August) is 7.2 inches. Soil moisture utilization in the profile was increased 1 inch by the addition of 60 pounds of N. Maximum moisture use occurred during the time the plant was making rapid elongation.

At Bushland, Texas, water use with blue grama was the same on plots receiving N, which yielded 7,000 pounds forage per acre, as on the plots not treated, which yielded 1,310 pounds. Water use efficiency was increased more than fivefold by applied nitrogen.

On a range study near Riverside, California, the application of N and P gave 54 and 98 additional pounds of dry range forage per inch

of moisture used on a rocky slope and a swale site, respectively. Either element applied alone did not increase yield.

In a N uptake study at different moisture levels at Mandan, North Dakota, water use efficiency was increased severalfold in bromegrass by the use of nitrogen. Rooting depth and moisture extraction was deeper on the N-treated plots, and seasonal water use was an inch greater than the check treatment.

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AREA 10 SOIL PROPERTIES, PROCESSES, AND MANAGEMENT IN RELATION TO THE CONSERVATION AND EFFICIENT USE OF LAND AND WATER RESOURCES

Problem. Soil and water conservation practices developed by action agencies for use on farms depend on sound technical information. Because of the lack of fundamental data, many of the recommended practices today are being developed without the benefit of this information. Most of the conservation practices are in one way or another affected by the structural attributes of the soil. However, at present there are no fully accepted methods for quantitatively assessing this important soil property. Fundamental mechanisms of soil structure formation must be understood before residue management systems, tillage methods, and cropping systems can be developed that will improve and preserve soil tilth. Each year 1.25 billion dollars is spent by the American farmer for commercial fertilizer. Recommendations for its use have to be made without a knowledge of the solubility of nutrients from different sources, or the influence of one element on the availability of other essential elements. Large losses of fertilizer N are known to occur by chemical and microbial denitrification and by ammonia volatilization. Field experiments show that N recovery by crops can be as low as 25 or as high as 87 percent of that applied. Much more quantitative information is needed on factors affecting mineralization of soil N and residual N so that sound tests for predicting fertilizer requirements of crops can be developed. Since many of the pesticides and growth regulators used today in agriculture are applied directly to the soil or ultimately reach the soil, the fate of these chemicals in the soil must be understood in order to predict what might happen with their continued use.

USDA PROGRAM

The Department has a continuing long-term program involving microbiologists, chemists, plant physiologists, and physicists working on basic studies and the application of known principles to soil and water conservation problems. Some of the work is centered at the U. S. Soils Laboratory, Beltsville, Maryland. Nutrient requirements-uptake and balance research is being conducted at New Brunswick, New Jersey, Ithaca, New York, Beltsville, Maryland, Thorsby, Alabama, Watkinsville, Georgia; Rio Piedras, Puerto Rico; Florence, South Carolina, State College, Mississippi, Morris, Minnesota, Ames, Iowa, Fort Collins, and Grand Junction, Colorado, Huntley, Bozeman, and Sidney, Montana, Newell, South Dakota, Bushland, Weslaco, and Big Spring, Texas, University Park, New Mexico, Tucson, Arizona, Brawley, California, Prosser, Washington, and Pendleton, Oregon.

Research concerned with soil chemical properties is being conducted at Beltsville, Maryland, State College, Mississippi, Auburn, Alabama, Rio Piedras, Puerto Rico; Watkinsville, Georgia; Morris, Minnesota; Fort Collins, Colorado, Mandan, North Dakota, Weslaco, Texas, Prosser, Washington, and Corvallis, Oregon.

Tillage, residue management, and cropping systems research is being conducted at Orono, Maine, Ithaca, New York, State College, Pennsylvania, Blacksburg, Virginia, Florence, South Carolina, Watkinsville, Georgia, Morris, Minnesota, Ames, Iowa, Minneapolis, Minnesota, Akron, Colorado, Bozeman, Montana, North Platte, Nebraska, Newell, South Dakota, Sidney, Montana, Mitchell and Lincoln, Nebraska, Bushland, Big Spring, and Temple, Texas, Woodward, Oklahoma, Pendleton, Oregon, and St. Anthony, Idaho.

Soil microbiology research is being conducted at Beltsville, Maryland, Minneapolis, Minnesota, Fort Collins, Colorado, Lincoln, Nebraska, and Prosser, Washington.

The Federal scientific effort devoted to research in these areas totals 96.3 professional man-years. Of this number, 29.3 are devoted to nutrient requirements-uptake and balance; 18.2 to soil chemical properties; 40.0 to tillage, residue management and cropping systems; and 8.8 to soil microbiology. At all locations the work is done in cooperation with the Experiment Stations in the respective States

RELATED PROGRAMS OF STATE EXPERIMENT STATIONS AND INDUSTRY

State Experiment Stations in 1961 reported a total of 254.1 professional man-years divided as follows: Nutrient requirements - uptake and balance, 146.3; soil chemical properties, 37.4; tillage, residue management and cropping systems, 50.2; and soil microbiology, 20.2. The State Experiment Stations also report 62.9 man-years on research effort in soil morphology and genesis relating to classification. All of the State stations have research in progress on nutrient relationships of soils. Studies concerning time, rate and placement of fertilizers for different soil and crop conditions are included. Research designed to provide a better understanding of chemical properties of local soils is in progress at many of the State stations. Some research is in progress at State stations to evaluate the physical conditions in the soil that are essential for soil and water conservation. Soil microbiological investigations are being conducted at most State stations with major emphasis being placed on nitrogen transformations in the soil.

Industry and other organizations. Several chemical companies are conducting research to screen and test various chemical compounds that may prove effective in the field of soil and water. Inoculant manufacturers are doing a limited amount of research to improve their cultures. It is estimated that this research is equivalent to 25 professional man-years.

REPORT OF PROGRESS FOR USDA AND COOPERATIVE PROGRAMS

A. Nutrient requirements - uptake and balance

Recovery of Applied Nitrogen. Results of greenhouse experiments conducted at Beltsville to study soil N uptake at various fertilizer N levels have shown that the uptake of soil nitrogen by oats increased with increasing rates of fertilizer nitrogen. The maximum effect of N application on the uptake of soil N for the 12 soils studied averaged about 30 percent above the control. The percentage uptake of fertilizer nitrogen also increased with rate of application. Present evidence indicates that such differences in nitrogen uptake can be best explained by the differential immobilization of mineral nitrogen by rhizosphere micro-organisms in the utilization of energy material derived from roots of varying carbon-nitrogen ratios.

The Beltsville Laboratory has cooperated at Thorsby, Alabama, on a field experiment in which N^{15} nitrogen fertilizer was used to study movement and recovery of fertilizer nitrogen. From 10-15 percent of the added N^{15} could not be recovered from the plants or soil, so it was assumed to have been lost in the gaseous form. Recovery from cropped soil was somewhat greater than from uncropped soil. Nitrogen recovered was not influenced by time of application or the ammonium sulfate or sodium nitrate sources. Recovery from uncovered plots was as high as from plots protected with plastic covers.

In studies of the fate of 640 pounds of nitrogen applied to crested wheatgrass at Newell, South Dakota, nitrate-nitrogen analyses accounted for one-third of the fertilizer nitrogen on irrigated plots and over two-thirds of the fertilizer-nitrogen on the dryland plots after one winter and one cropping period. Considerable fertilizer nitrogen could not be accounted for in the soil nitrogen fractions studied. Wide differences in unaccounted for fertilizer nitrogen existed between irrigated and dryland plots. Variance ratios for the irrigated plots for soil depths from 0 to 18 inches indicate no significant fertilizer treatment effects on the ammonia-N, hydrolyzable ammonia-N, amino acid-N, or the residue-N fractions. Considerations of the amounts of unaccounted for fertilizer nitrogen in comparison to native soil nitrogen illustrate the difficulties involved in trying to determine balance sheet figures.

Nitrogen recovery by Bahia and Coastal Bermudagrass was studied over a 6-year period at Thorsby, Alabama, both under nonirrigated and irrigated conditions. The percent recovered by Coastal under irrigation varied from 87 percent at the 300-pound annual N rate to 76 percent at the 900-pound rate. On the nonirrigated treatments, the percentage recovered was about 10 percent less than for the irrigated treatments. Coastal recovered a higher percent of the applied N than Bahia.

Plastic coatings on nitrogenous fertilizers show great potential for increasing the recovery of applied N in the Rio Grande Valley. At Weslaco, Texas, coated urea at the rate of 90 pounds of N per acre increased yields of sweet bell peppers by 12,880 pounds as compared to an increase of 690 pounds with a like amount of uncoated urea.

Loss of ammonia dissolved and applied to fields in irrigation water was studied at Brawley, California. The loss in the ditch was 2 percent in 1,500 feet and in the furrow was 4.3 percent per 100 feet. Temperature had little apparent effect on these losses. The loss in furrows was decreased by increasing the flow rates.

In a nitrogen laboratory study at Fort Collins, Colorado, results showed that the standard Kjeldahl procedures include only a portion of the indigenous fixed N ammonia in soils high in this fraction. Pretreatment with HF before Kjeldahl analysis includes this fraction.

Mineralization of Nitrogen. At Mandan, North Dakota, laboratory studies showed the marked effects of soil moisture tension on the ammonification and nitrification processes in two soils. Both processes are slowed substantially at the comparatively low tension of one bar.

At Fort Collins, Colorado, a study has been made of the extent to which four organic materials, two containing amino nitrogen and two entirely nonnitrogenous, facilitate the dismutation of nitrous acid in soil and sand substrates. Their order of decreasing effectiveness in promoting nitrite dismutation in either substrate was found to be: ascorbic acid > glucosamine > glycine > glucose. Mineral nitrogen deficit in the substrate exceeded 50 percent of the initially added nitrogen following addition of ascorbic acid, glucosamine or glycine, but amounted to only 10 percent in the glucose-treated soil. Only ascorbic acid and glucosamine led to release of gaseous nitrous oxide; molecular nitrogen was evolved from all four treatments, although only scantily so with the glucose treatment. Picolinic acid restricted the first stage of the nitrification process, the oxidation of ammonia to nitrite, but did not restrict the second stage, the oxidation of nitrite to nitrate.

A satisfactory sampling technique and analytical procedure using gas chromatography has been devised and used to measure the oxygen and carbon dioxide contents of the soil atmosphere. This technique has been used on soil in laboratory lysimeters to measure composition of the soil atmosphere with particular reference to the factors of soil depth and length of incubation. Such studies are essential to understanding some soil nitrogen transformation.

The increasing use of anhydrous ammonia as a nitrogen fertilizer has emphasized the need for more basic information on the processes of fixation of NH_3 and NH_4 by the mineral and organic fractions in soil. Previous work at Corvallis, Oregon, has shown the extremely wide range of fixation of ammonia by different soils and soil horizons. Continuation of these studies has included the NH_3 and NH_4 fixing behavior of silicate minerals in selected soils of the Pacific Northwest as compared to reference layer-silicate minerals, under a wide range of fixing conditions. Results support the conclusion that a continuous gradation of fixing minerals occurs in these soils and that simple characterization of the dominant clay minerals is insufficient to predict fixation characteristics.

Influence of Soil Texture on P Requirements. Studies conducted at Fort Collins, Colorado, show that the effect of soil texture on available P and the amount of fertilizer P needed to produce equal rates of P uptake could be explained more adequately by applying the concept of diffusion of P. Differences in rates of uptake predicted from diffusion equations were observed in actual measurements of rates of P uptake by plants. As a result of this approach, a sound basis is provided to develop a method for determining the amounts of fertilizer phosphorus needed to give equal levels of available phosphorus on soils varying in texture. A clay soil requires two to three times as much fertilizer phosphorus as a fine sandy loam (calcareous or alkaline soils) to produce the same plant response when both soils are initially very low in available phosphorus. An exact quantitative evaluation of this textural effect has not been possible because of variations in maximum yields among soils.

Influence of N on the P Requirements. Short-term phosphorus uptake studies were conducted at Fort Collins, Colorado, with intact month-old corn plants of differential nitrogen and phosphorus composition. Supplemental nitrogen pretreatments producing increased growth rates and higher levels of nitrogen in the plant, stimulated the rate of phosphorus uptake per gram dry weight of root more than tenfold. The presence of nitrate or ammonium ions in the test solution during the uptake period had negligible effects on phosphorus uptake rates. The increases in phosphorus uptake rates may be general effects of the increasing demand for phosphorus within the plant with increased growth rates, but the magnitude of these effects suggests a more direct connection. Phosphorus uptake rates were highly correlated with total nitrogen level in the root.

Influences of Stage of Plant Growth and Soil Moisture Tension. Results of study on the influences that stage of barley growth and soil moisture tension have on the absorption of P conducted at Bozeman, Montana, showed that most of the P was absorbed by barley in the tillering to heading stage. No P was absorbed from a soil near the wilting point. However, uptake started eight hours after the soil was

brought to field capacity on a fine sandy loam soil and after 32 hours on a silty clay loam. A high moisture zone did not aid the plant in removing P from an adjacent low moisture zone.

Wheat and intermediate wheatgrass growing in nutrient solution treatments that had phosphorus withheld for the first 3 weeks and then supplied for the remainder of the growth period, gave much less than the plants supplied with P for the first 5 weeks and then was withheld for the remainder of the growth period.

New Method for Determining Exchangeable P. The accuracy of exchangeable phosphorus measurements for soils varying in their phosphate-fixing capacity was investigated at Fort Collins, Colorado. After equilibrating the soil with tagged solutions, P^{32} recovery was measured by the resin adsorption method and the specific activity of phosphorus on the resin was compared with that of the equilibrium soil extract. In some soils the specific activity of phosphorus on the resin was higher than that in the equilibrium solution. This indicated that during the equilibration period some P^{32} was taken up by the soil in a form which was no longer exchangeable with phosphorus in solution. The appearance of nonexchangeable P^{32} during extraction increased with the phosphate-fixing capacity of soil and led to overestimation of exchangeable phosphorus, especially in the carrier-free method. The addition of carrier phosphorus tended to reduce the error due to non-exchangeable P^{32}. A method that involved equilibrating the soil with 100 ml of 0.2-ppm phosphorus solution was recommended and proved satisfactory for determining exchangeable phosphorus in low- and medium-fixing soils. The equilibration period was limited to 30 minutes to reduce the effect of recrystallization and self-diffusion and to avoid any changes that may take place in the soil system during long equilibration periods.

Movement of P in the Soil. At Tucson, Arizona, P applied at a rate of 500 pounds per acre moved about 1.5 inches in the soil during a season. Phosphorus movement was the same in soil textures varying from fine loamy sand to silty clay loam and with seasonal irrigation applications varying from 3 to 12 inches. Water insoluble phosphates and lower application rates (50 pounds P per acre) reduced the movement by a half inch or less.

Interrelations Between Cation and Anion Uptake. Current trends for the higher use rates of fertilizer in crop production have imposed new parameters on the concept of nutrient balance and absorption in relation to yield. At Beltsville, Maryland, the interrelations between cation and anion uptake and content of plants have been reexamined. Under conditions where high amounts of fertilizers are used, research results show that the main function of cations is to supply positive charges which enables the plant to maintain the pH and the organic acid content within a narrow range, and that this is a prerequisite

for good growth. This information will allow a more rationalized method for composing fertilizer mixtures to be developed.

A direct physical picture of the pathway of ion uptake in the plant roots is needed to clarify the role of the soil as a source of nutrients in relation to the ion uptake process by the plant root. Techniques have been developed for preparing high resolution autoradiographs. This is the first step in determining the initial sites of ion entry and accumulation.

Fertilizer Application. In an experiment to study the effects of nonuniform fertilizer distribution on corn yields in South Carolina, results showed that fertilizer distribution could vary as much as 40 percent from uniformity without causing a significant yield decrease. In this study all whole plots received the same amount of fertilizer but the distribution pattern in rows varied.

At Big Spring, Texas, deep placement of fertilizer on cotton showed no advantage over placement at conventional depths. Subsoiling and deep placement of lime and fertilizer to stimulate deep root growth have not increased vegetable crop yields on a coastal plain soil in New Jersey. On range grasses at Mandan, North Dakota, and Newell, South Dakota, there were no yield differences due to method of fertilizer application.

In Georgia, moderate rates of potassium applied after each cutting to Coastal Bermudagrass maintained a more nearly optimum level of production and nutrient content in the plant than a single annual application. In Puerto Rico, yield and protein content of Guinea grass were more uniform throughout the year when the nitrogen and potassium fertilizer were applied in 4 or 8 equal applications rather than split into two applications.

Studies on time of application of nitrogenous fertilizers to maintain meadows in western Wyoming showed that fall application was not as effective as spring or spring-summer application at two locations out of four. Nitrogen source made no difference in increasing yields, and 80 pounds of N per acre more than doubled yields regardless of when it was applied.

Studies on the availability of residual nitrogen from applied ammonium nitrate fertilizer to summer fallow wheat were continued at Pendleton, Oregon. Where more than 80 lb/A. N were applied for the 1959 crop, sufficient residual N was available to increase yields of the next (1961) wheat crop. It now appears that successive applications of about 40 to 50 lb/A. N on each wheat crop is adequate to maintain maximum yields in the 15- to 16-inch rainfall area. In the 11- to 12-inch rainfall area, about 30 lb/A. N appears to be adequate.

In western Minnesota, eastern North Dakota, and eastern South Dakota, a combination of management practices that should give the most efficient use of soil moisture are being studied. About one-half of the locations showed a response to variations in corn population, one-third to nitrogen additions, and one-fourth to phosphorus additions. In 1960, good correlations between corn yields and the amount of moisture stored in the soil at planting time were obtained. However, in 1961, rainfall during the growing season was a better indicator of crop yields.

At Riverside, California, in a dryland alternate fallow-grain system, both a knowledge of available soil moisture and nitrogen (or potentially available) at planting time are required in predicting what the effect of applied nitrogen will be. On a rangeland study in a season with one-third average annual rainfall, the soil moisture was more efficiently used when 60 pounds of nitrogen and 14 pounds of phosphorus per acre were applied.

Micronutrients. A serious growth abnormality in Russet Burbank potatoes in the Columbia Basin Irrigation Project has been diagnosed as a zinc deficiency by research conducted at Prosser, Washington. This deficiency, occurring on areas on newly leveled land, was aggravated by applications of phosphate fertilizer. The deficiency was corrected by supplementing the necessary N plus P fertilization with 10 pounds Zn per acre applied as $ZnSO_4$.

Iron is more often deficient in plants than any other minor nutrient element. At Beltsville, Maryland, the compounds keeping iron in a soluble form in plants have been identified. Exudates were collected from normal and iron deficient plants. The combination of iron was established by electrophoresis and found to be chiefly with two plant acids, malic and malonic. The varying capacities of roots to reduce iron before it has been absorbed has been demonstrated. After the iron enters the plant it is again oxidized.

In the first year of studies at Pullman, Washington, on the cause and control of the "alfalfa sickness" problem a marked growth response and effective nodulation was obtained when P, S, and lime were applied and when the soil profile was mixed to a 4-foot depth. No response occurred on the soil aeration or vertical mulching treatments.

At Prosser, Washington, studies are being conducted to determine the importance of silicates in the fixation of soluble zinc. Results show that zinc silicates, including the montmorillonite-type layer, have been synthesized from dilute solutions at 95° C. but not at room temperature.

Nutrient Requirements of Subsoils. Exposed subsoils due to erosion, land forming, and road building are presenting an array of problems. In Mississippi, the fertility requirements for soil type varied, with several being deficient in sulfur. Subsurface horizons of four important Delta soils were less productive than corresponding surface horizons regardless of fertilizer treatment. At Cartersville, Georgia, lime, N, P, and K were essential for the development of adequate plant cover on subsoils exposed in road cuts. Experiments involving subsoils from the Southern Plains conducted at Bushland, Texas, have shown that the subsurface horizons can be made as productive as topsoils through the application of fertilizers. Results from Iowa vegetation studies on subsoils emphasized the need for mulch to prevent crust formation on clay subsoils in addition to large amounts of fertilizer and lime. Severely eroded plots of Honeoye soil in New York that were liberally fertilized and well managed, yielded only 10 percent less than the comparable noneroded plots.

Influence of Fertilizer on Leaf Area Index. At Huntley, Montana, leaf area index (ratio of leaf area to soil area) of sugar beets was increased by nitrogen fertilization but was little affected by beet spacing in the row (6, 12, or 18 inches). Nitrogen fertilization increased beet yields 1.5 tons an acre, and yields for the 6-, 12-, and 18-inch spacings were 17.1, 18.0, and 20.0 tons an acre. Sugar content and thin-juice purity were both lowered by nitrogen fertilizers. Leaf area index and leaf area per beet were negatively correlated with sugar content and purity. After August 1, beets lost leaf area unless given more nitrogen fertilizer. This comprehensive study of leaf area, yields and sugar content as affected by nitrogen fertilization and plant spacing, when fully analyzed should yield the best data available in the United States on the physiological relationships of leaf area to sugar accumulation as affected by soil management variables.

B. Soil chemical properties

Soil Chemistry Associated with Applied Herbicides. At Beltsville, Maryland, the experiments to determine the fate of herbicides applied to the soil have continued. When soil columns were wetted from above with a saturated 5 ppm aqueous simazin solution, 48 percent was retained in the top inch and 6 percent in the fifth inch. After incubation in soil for a week, only about half of the added herbicide could be removed. The amount retained at pH 4.7 was 28 percent greater than at pH 4.5. Concentration of simazine absorbed by H-montmorillonite and Ca-montmorillonite were about 2.0 and 0.4 percent, respectively. An X-ray defraction pattern indicated that the herbicide entered the interlayer space.

Influence of Soil Reaction on Plant Growth. The response of crops to lime in the Southeastern States is well distributed throughout the Coastal Plain, Piedmont, Loess Belt, and the Coastal Flatwoods

regions. Experimental stands of alfalfa and clover have completely disappeared on no-lime plots at several locations. At Thorsby, Alabama, molybdenum increased stand persistence of alfalfa at low lime rates. Recently, crops normally thought to be acid tolerant have responded to lime. Lime increased yields of Coastal Bermudagrass in Alabama, Georgia, and Mississippi; Napier grass and coffee in Puerto Rico; and soybeans in Georgia and North Carolina.

Studies of subsoil acidity associated with the use of high rates of residually acid nitrogen fertilizer at Watkinsville, Georgia, show that considerable downward movement of bases have occurred. In Puerto Rico, calcium moved down as much as two feet in the profile over a 3-year period when liming was followed by heavy applications of ammonium sulfate.

At Auburn, Alabama, in an experiment to determine the factors involved in root development in subsoils with low pH values and high levels of exchangeable aluminum, it was found that soybean roots were quite tolerant, cotton roots moderately tolerant, and Sudangrass roots very sensitive to these subsoil conditions. Marked improvement in Sudangrass root development in acid subsoils resulted from liming. In all cases the surface soil environment was favorable.

Aluminum toxicity studies conducted at Beltsville, Maryland, have confirmed that plants vary widely in their tolerance to aluminum. Buckwheat was found to be aluminum tolerant and a strong phosphorus accumulator, whereas barley was aluminum sensitive and a weak phosphorus accumulator. Corn, cotton, millet and mustard were intermediate. Beneficial efforts of phosphate and/or lime on a high aluminum, acid soil appear to be associated with increased phosphorus uptake.

Exchangeable Sodium and Salts Removed by Leaching. The Sebree soils of southwestern Idaho have compacted and cemented layers in the subsoil which are combined with high sodium in the surface layer and high salt levels throughout the profile. These layers greatly restrict water and root penetration. Plowing to a depth of 30 inches or more breaks up the dense layers and improves water intake, root penetration, and crop growth. The improved water penetration effectively leaches sodium and salts from the surface layers without the use of soil amendments. Complete reclamation occurs within 2 to 3 years using normal irrigation practices.

Separation of Minerals from Clay-Mineral Mixes. A major handicap in the study of clay minerals in soil systems is the present lack of adequate methods for the separation and quantitative estimation of individual minerals from clay-mineral mixes. Initial attempts at Corvallis, Oregon, to use continuous-flow paper electrochromatography for this purpose demonstrated that separation of montmorillonite from a mixture with kaolinite and vermiculite was possible.

C. Tillage, residue management and cropping systems

Soil Structure. Soil structure controls many of the responses of crop plants to soil management and conservation practices. Progress on the basic nature of the forces involved in holding soil particles in a stable crumb structure have been made at St. Paul, Minnesota. Evidence has been obtained that polysaccharide bonding is important in stabilizing natural soil aggregates.

In spite of the evident importance of the organic fraction of soil in the development and maintenance of soil structure, our present knowledge of the basic chemistry of organic matter is still fragmentary. Fundamental studies with modern methods and instrumentation have been initiated at Corvallis, Oregon, to investigate soil organic matter chemistry in detail. As a first stage in this research an intensive analysis has been made on a large number of Pacific Northwest soils describing their content of organic and inorganic carbon, total N, indigenous fixed NH_4, NO_3 nitrogen, organic nitrogen, and their C/N ratios, all in relation to horizons. These data will provide necessary and valuable background information for more detailed analyses of amounts and kinds of organic carbon-nitrogen compounds.

Tillage. Rapid progress has been made in the preparation of a tillage guide for the major soil types in the western Corn Belt. The guide provides for the first time a means, based on the soil characteristics created by tillage operations, whereby technicians can evaluate tillage practices. A set of soil parameters for the row and interrow zones has been developed for the guide.

A microrelief meter was designed and field tested from which soil surface roughness and surface elevation can be measured. Measurements made in 1961 with the meter shows that potential surface water detention is due to random depressions created among the large clods and to the patterns formed by tillage tools. In reduced tillage systems, such as wheel-track and listing, the potential water detention was more than twice as great as from conventional tillage.

Minimum tillage for corn has proved effective in studies in New York and New Jersey and on medium- and coarse-textured soils in Virginia. On clay soils in western Virginia, however, poor stands continue to be a problem. Corn following sod with no tillage, using either herbicides or black plastic to kill the sod, gave yields as high as conventionally tilled plots in Virginia and New York. Soil moisture was higher under the nontilled than under conventionally tilled plots.

Experiments on plowing 14 to 18 inches deep at Baton Rouge, Louisiana, indicated that sugar cane responded to deep plowing only in years of sparse seasonal precipitation.

Corn yields on Moody silt loam in Iowa have been higher on conservation tillage practices than on conventional practices under conditions of low soil moisture at planting and/or midsummer drouth. Under favorable moisture conditions, yields were not greatly different among the tillage methods tested.

Tillage Pans. Research results confirm that excessive strength of the tillage pans in the Southern Great Plains is the cause of reduced plant growth and yield. The soil strength is created by an increase in soil bulk density, a decrease in soil moisture content, or a combination of the two factors. At Woodward, Oklahoma, moldboard plowing deep enough to disrupt the tillage pans did not increase sorghum yields. Disking a compact Amarillo fine sandy loam to a depth of 8 inches decreased the strength to a desirable level, but chiseling to a depth of 10 inches only created a trench filled with low strength soil. Cotton roots developed normally in zones of low strength, but could not develop in zones of high strength.

Mulch Planting. In Mississippi, corn yields did not differ significantly when planted in mulch, tractor tracks, or a well-prepared seedbed. Six tons of corn residue left on the surface over winter and partially incorporated at planting time reduced growth, nitrogen uptake and yield of succeeding corn crop by about 25 percent. Plowing under the residues partially eliminated these reductions. The carryover of fall-applied nitrogen was the same for all residue management systems.

In South Carolina, soybeans planted directly in grain stubble and corn planted directly in Coastal Bermudagrass gave yields equal to those on conventionally prepared seedbeds. The yield and quality of plantains planted directly in sod followed by strip cultivation were as high as those produced with complete land preparation and clean cultivation on a latosal in a mountain region of Puerto Rico.

Wheat yields in Nebraska and Colorado and corn and oat yields in Nebraska have been less on stubble-mulched plots than on conventionally tilled treatments. Laboratory studies at Lincoln, Nebraska, show micro-organisms may produce phytotoxic substances which, in some cases, could account for yield reductions of wheat and corn.

Experimental results obtained at Ames, Iowa, demonstrate that crop residue mulches may decrease the availability of manganese needed for early growth of corn. Mulched corn plants sampled 25, 34, and 41 days after planting contained 81, 32 and 34 ppm of manganese, respectively, as compared to clean-cultivated plants with 145, 69, and 40 ppm.

At Cherokee and Woodward, Oklahoma, clean-tilled land outyielded stubble-mulched land when no fertilizer was applied, but yields on stubble-mulched land were equivalent or greater than on clean tilled when 40 pounds of N was applied.

Plastic Mulch. A transparent plastic mulch used at Marcellus, New York, increased soil temperatures and early plant growth. Corn yields on the control plot were 109 bushels as compared to plastic mulch yields of 124 bushels for the normal season hybrid and 134 bushels for the late hybrid. On plots with a sealed plastic cover, 113 bushels of corn per acre were produced with the estimated 6-8 inches of available water at planting time. At no time during the season was there evidence of moisture stress.

In northern Maine, heating cables and plastic mulches were used early in the season to increase the temperature under potatoes. In June and early July, soil temperatures on the plots with the heating cable were 10 to 15 degrees higher than on the control. Temperature under the plastic tended to be slightly lower than the heating cable treatments. Plants on the plots with higher temperature emerged two weeks earlier and flowered one week earlier than on the control. At harvest time tuber yields were the same for all treatments.

At Prosser, Washington, sweet corn was matured one week earlier by planting under clear plastic. Soil temperatures were increased under the clear plastic and reduced under the black plastic as compared to plots without cover.

Cropping Systems. Corn yields in a corn-Coastal Bermudagrass rotation at Florence, South Carolina, were no higher than those on continuous corn. In the Georgia Piedmont, rotations with legume sod crops increased corn yields by 10 to 20 bushels per acre as compared to the continuously cropped plots, even when 80 pounds of nitrogen was applied.

Rotation experiments in the Southern Plains have shown that two years of alfalfa or sweetclover increased dryland corn yields at Temple, Texas. Two years of Rhodesgrass in an irrigated rotation at Weslaco, Texas, did not increase cotton yields significantly nor did it change moisture utilization or root growth patterns. At Bushland, Texas, the fourth irrigated grain sorghum crop following two years of alfalfa averaged 500 pounds per acre more than continuous sorghum. At Cherokee, Oklahoma, alfalfa in an alfalfa-wheat rotation supplied sufficient nitrogen for maximum yields of wheat for two years following alfalfa, but nitrogen deficiency developed in third-year wheat.

In north central North Dakota the effect of nitrogen and phosphorus fertilization on crop yields under irrigation was evaluated in a non-legume rotation (barley, corn, potatoes) and in a legume rotation

(barley, alfalfa, alfalfa, alfalfa, corn, potatoes) on Gardena loam. In the nonlegume rotation, yields of all crops were increased by nitrogen. Phosphorus alone decreased yields of corn forage. However, with adequate nitrogen, phosphorus increased yields of barley, corn, and potatoes. In the legume rotation, the major effect of alfalfa was to supply available nitrogen.

Maintaining legumes in permanent grassland in the Northeast is a difficult task. Legume-grass mixture studies conducted at the U. S. Pasture Laboratory, State College, Pennsylvania, have shown that competition below ground was more serious than competition above ground. Results do not support the hypothesis that established grasses secrete a substance toxic to legumes. Field experiments show that the legumes in mixtures suffer from lack of water in many cases.

In Puerto Rico, kudzu-molasses grass pastures were established on shallow, eroded Mucara clay with 50 percent slope in the humid mountain region. Rotation grazing of pastures furnished the entire ration for the grazing animals. On these pastures, erosion has been stopped and soil organic matter increased.

Studies at Akron, Colorado, of the interrelationships of soil and climate as a basis for predicting applicability of research results have shown that soils with the thin solum phase yielded less than profiles with deep surface horizons.

A study of wheat yields grown on fallowed land at Akron, Colorado, revealed that yields of wheat were essentially zero when the precipitation for the 2-year period was 24.5 inches or less. The average amounts of precipitation required above the base to produce a bushel of wheat were 0.36 inch during the period 1941-1954 (normal); 0.67 inch during the period 1908-1929 (normal); and 2.7 inches during the period 1930-1940 (drouth period), respectively.

D. Soil microbiology

Decomposition of Crop Residues. Marked toxicity of rye grass was observed in experiments conducted with soils from the Southeastern States that had been heavily fertilized with green manure and commercial fertilizers. The most likely cause appeared to be the accumulation of nitrite. In experiments conducted at Beltsville, Maryland, using three Coastal Plain soils, up to 80 ppm of nitrite-nitrogen and 110 ppm of ammonia-nitrogen were observed on treatments which received 10 tons alfalfa and 180 pounds N per acre. The amounts measured in the three soils varied greatly. In some instances the ammonia concentrations were probably high enough to retard the oxidation of nitrite to nitrate-nitrogen. Additions of garden soil inoculant decreased the time that the nitrite was present.

At Beltsville, Maryland, corn residues labeled with C^{14} were used to study the influence of green manure on the oxidation of native soil carbon. Results showed that mature corn leaves and stalks did accelerate the oxidation of native carbon but that mature roots or immature whole corn plants reduced the oxidation.

Decomposition of Wood and Bark. In a study of the decomposition rates of 28 species of woods and barks at Beltsville, Maryland, woods decomposed twice as fast as bark. The softwoods behaved very erratically but most were less readily attacked by micro-organisms than were the hardwoods. The nitrogen requirements for decomposition expressed as percentage of the wood added was 0.61 percent for the softwoods and 1.24 percent for the hardwoods. Results emphasized the necessity of knowing the species of wood being added to the soil if nitrogen fertilization is to be regulated economically.

Antibiotics. Detecting antibiotics in soils has been a difficult task. Studies at Beltsville, Maryland, have shown that only basic and amphoteric antibiotics are absorbed by soil and clay minerals. The basic ones, through the action of buffers, are released only from kaolinite, whereas the amphoteric ones are released from kaolinite, montmorillonite, vermiculite and illite.

Influence of Soil Drying on Microbial Action. In a nitrogen-mineralization study more CO_2 and nitrogen were released when soil was incubated after drying than when kept moist prior to incubation. The effect increased with length of time of dry storage. This effect is apparently the result of physical and chemical changes that render the organic matter more accessible to microbial action. The effects of drying on microflora were of minor importance. Samples kept dry for 27 weeks before incubation evolved 38 percent more CO_2 and mineralized 5.7 to 10 percent more nitrogen than samples incubated immediately after drying.

Modifying Bacterial Strains with New Techniques. A study is underway to find methods for modifying bacterial strains, especially the rhizobia, using genetic techniques that have been developed in recent years. In previous studies the modification of strains has been attempted by means of transduction techniques where the genetic material, DNA, is transferred from cell to cell by means of a phage. More recent developments in the field indicate that transformation techniques are more likely to be successful. This involves the chemical extraction of the DNA followed by growth of organisms in contact with it. In order to follow any changes or mutations that occur, it is necessary to have markers. Purified DNA was prepared from eight strains of mutants. Transformation experiments indicated that the markers in these strains could be transferred by the purified DNA.

Influence of Plant Residue Decomposition on Root Disease Control. Decomposition of plant residues is known to have a pronounced effect on the survival of plant pathogenic micro-organisms in soil, but not enough is known about this effect to make use of it in management practices for root disease control. In continuing attempts at Prosser, Washington, to understand these processes, it has been found that decomposition of plant residues in soil in the absence of oxygen is quickly lethal to the fungus causing the verticillium wilt disease of potatoes. Prolonged anaerobic fermentation leads to drastic reduction in the populations of soil fungi in general, suggesting that other root pathogens may be similarly destroyed. The effect appears to be due to the production of fermentation products that are fungitoxic. The controlled production of anaerobic conditions in soil may be a feasible control practice against these disease producing soil organisms.

Other laboratory studies at Prosser, Washington, have produced mutant strains of the soil-inhabiting potato-scab organism that have high resistance to the antibiotic streptomycin yet retain their pathogenic abilities. This finding furnishes evidence that this process may occur in soil, indicating that soil treatment with fungicides may lead to the appearance of new resistant strains.

Selecting and Storing Nitrogen-Fixing Rhizobia. Preliminary results obtained by field studies in 1961 indicated that most of the nodules formed on soybean plants grown in areas with a large population of soybean organisms are formed from those already in the soil and not from the inoculum. This emphasizes the need for selecting highly competitive and high nitrogen-fixing strains for use as inocula. This problem has been attacked by classifying the rhizobia into serological groups and by taking advantage of the fact that many strains of soybean nodule bacteria produce chlorosis.

The longevity and nitrogen-fixing ability of cultures of rhizobia that had been stored for periods of 5 to 45 years were determined. Three methods of storage were involved; namely, the usual system of storage on agar at $4^{\circ}C$ with semi-annual transfers to fresh agar; storage on agar under paraffin oil, and storage dry after lyophilization. All lyophilized cultures were alive after periods of five years but not all were effective in nitrogen fixation. Twenty-nine percent of 652 cultures stored under oil for 7 to 8 years were viable but some were negative with respect to nitrogen-fixing ability. There were also marked variations between the behavior of cross-inoculation groups.

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AREA 11 SOIL, WATER, AND PLANT RELATIONS AS THEY AFFECT USE OF LAND AND WATER RESOURCES

Problem. In order to develop management practices that will beneficially use the energy from the sun in soil and water conservation, the relationship between climate, soil, and plant growth must be understood. The immediate climatic environment around the plant and at the soil surface has a profound influence on the growth of the plant and the loss of water from the soil and plant. It is generally accepted that only 1 to 2 percent of the sun's energy is actually used by the plant to manufacture food. A portion of the remaining energy is used for evaporation of water from the plant and soil. Since the heat budget cannot be violated, an increase in the use of solar energy for photosynthesis represents a means of utilizing energy that is otherwise used in evaporation of water. This important relationship opens a wide vista of possible approaches to the problem of conservation of moisture.

The effect of crop geometry and microrelief on the loss of water by evaporation and the transfer of heat from the plant and soil needs to be understood. Information is also needed on the exchange of radiation, heat, water vapor, and carbon dioxide between the crop and the atmosphere.

USDA PROGRAM

The Department has a continuing long-term program involving soil physicists, soil chemists, plant physiologists, and engineers engaged in both basic studies and the application of known principles to the solution of soil and water problems. Research conducted to study the relation of physical properties of soil on the movement of water to and into plant roots is being done at Ithaca, New York, Urbana, Illinois; Columbus, Ohio; Fort Collins, Colorado; Manhattan, Kansas; Tempe, Arizona, and Riverside, California. Research concerned with the determination of plant-soil-meteorological interactions involved in the movement of water in plants and the exchange of water, heat, and carbon dioxide between plants and the atmosphere is being conducted at Ithaca, New York, Watkinsville, Georgia, Thorsby, Alabama, Morris, Minnesota, Urbana, Illinois, Weslaco and Bushland, Texas, Manhattan, Kansas, and Tempe, Arizona. Research for the development of soil and crop management practices for maximum energy conversion is being conducted at Ithaca, New York, Thorsby, Alabama, Morris, Minnesota, Urbana, Illinois, Bushland, Texas, Manhattan, Kansas, and Tempe, Arizona.

The Federal scientific effort devoted to research in this area totals 22.6 professional man-years. Of this number, 12.5 are devoted to relating the physical properties of the soil to the movement of water to and into plants; 7.0 to determining the plant-soil-meteorological interactions involved in the movement of water in plants and the exchange of water, heat, and carbon dioxide between the plants and the atmosphere; and 3.1 to developing soil and crop management practices for maximum energy conversion.

RELATED PROGRAMS OF STATE EXPERIMENT STATIONS AND INDUSTRY

State Experiment Stations in 1961 reported a total of 41.2 professional man-years which, divided among the subheadings, is as follows: Relating the physical properties of the soil to the movement of water to and into plants, 32.5; determining the plant-soil-meteorological interactions involved in the movement of water in plants and the exchange of water, heat, and carbon dioxide between the plants and the atmosphere, 5.9; and developing soil and crop management practices for maximum energy conversion, 2.8.

Industry and other organizations. Industry activity in this field is confined to canning companies carrying on research to study the effects of microclimate on crop quality and harvesting dates. This work covers a small segment of the field of soil, water, and fertilizer research.

REPORT OF PROGRESS FOR USDA AND COOPERATIVE PROGRAMS

A. Relation of the physical properties of soil to the movement of water to and into plant roots

Influence of Soil Physical Problems on Water Movement. At Ithaca, New York, a theoretical study of the constant drying process of a bare soil (surface wet) was conducted which took into consideration the fact that diffusivity is an exponential function of moisture content. The new mathematical functions discovered will facilitate further studies and the determination of desorption parameters from observations made in nature.

At Auburn, Alabama, the permeability of surface crusts to water was found to be only about one-tenth of that of the soil material beneath the crust. The surface sealing affected by crusts accelerated runoff and reduced seedling emergence.

At Riverside, California, a simple method for measuring diffusivity and conductivity in the intermediate suction range from about 0.02 to 0.7 bar has been developed. This method involves the use of tensiometers and does not require a fully equipped soil physics laboratory. A chief advantage is that it provides the retentivity and the conductivity over this range of suctions in a much shorter time than other procedures.

At Tempe, Arizona, the diffusion coefficient of tritiated tracer water was determined in agar gel, moist soils, and glass beads preliminary to studies of water absorption of plant roots in soils. The experimental results for the homogeneous materials agreed closely with the theoretical diffusion equation. The diffusion coefficient of tritiated water (D_{THO}) in dilute agar gel is 2.16×10^{-5} cm^2/sec and in the moist glass beads is 1.56 and 1.69×10^{-5} cm^2/sec at 35.9 and 17.8 percent water content, respectively; and the D_{THO} for soils is on the order of 1.0×10^{-5} cm^2/sec. In the Pachappa loam soil, in which the D_{THO} was investigated more thoroughly, the D_{THO} was found to be a function of the amount of water in the soil. The diffusion coefficient is essentially constant at 1.14×10^{-5} cm^2/sec between 12 and 40 percent moisture content, has a maximum value of about 4.0×10^{-5} cm^2/sec at approximately 3.5 percent and has intermediate values between 1.5 (air-dry) to 3.5, and 3.5 to 10.0 percent moisture contents. The results bring up some thought-provoking questions in regard to vapor and liquid diffusion in soils, soil-water properties and the use of tritium tracer in water movement studies in unsaturated soils.

Influence of Soil Moisture on Diffusivity. At Manhattan, Kansas, a study to determine the influence of variations in diffusivity on infiltration showed that variations on the wet end of the moisture range influenced infiltration considerably, but large variations on the dry end had little influence on infiltration. These results indicate that accurate estimates of infiltration require accurate knowledge of the diffusivity at high moisture contents but not at low moisture contents.

At Fort Collins, Colorado, experimental results showed that a major portion of variation in water stability of soil aggregates was associated with the contact angle of water with the mineral surfaces. This work indicates that decreasing clay-water affinities is as important as increasing bonding between particles in improving the water stability of soil aggregates.

At Riverside, California, successful procedures have been developed to use a radial-flow-type pressure cell for measurements with soil samples having undisturbed structure. It should now be feasible to obtain more nearly adequate amounts of reliable data for soil-water retentivity, capacity, diffusivity, and capillary conductivity. Scarcity of such data is hampering the application of quantitative theories to soil-water management problems on saline soils. A theoretical analysis has shown that a good approximate relation between the soil-water diffusivity and the water content can be obtained from the instantaneous outflow rate from a pressure membrane apparatus for as large a pressure increment as desired. Thus, the diffusivity can be calculated from routine measurements of the retentivity. The method can also be used to obtain diffusivity on many soils merely by

measuring their rate of drying under a high potential evaporation rate. This shows promise as a field method.

In Illinois, a new technique has been developed for measuring soil moisture diffusivity. The method uses a cylindrical geometry and promises to be especially valuable in evaluating soils that have large swelling and shrinking properties. Also at Illinois, a strain-gage tensiometer has been developed which enables highly accurate determination of moisture potential in fast-changing systems.

In Ohio, a technique has been developed for describing the hydrodynamical problem of the drainage of sloping land. An analog was developed and used for a particular solution. The use of a resistance network in the solution of further problems of sloping land now appears feasible. Also at Ohio, electrical techniques for measuring and recording water table elevations have been developed.

At Riverside, California, progress has been made in designing a thermocouple psychrometer for use in soil in place in the field. Present methods for measuring the energy status of soil-water require that samples be brought into the laboratory. A field device should remove much of the sampling error and give much more reliable data upon the changing status of the soil-water as it is depleted by the plant.

Research has been carried on at Riverside on a more rigorous analysis of the drying of a soil under different constant evaporative conditions. A better basis has been obtained for predicting how long after wetting actual evaporation from a soil will equal potential evaporation. An approximate solution of the isothermal flow equation for the falling rate period of drying has also been obtained, indicating that the cumulative evaporation depends mainly upon the water content of the soil and only slightly upon the potential evaporation conditions. While the isothermal flow equation does not take into account many important effects, it describes the gross features of the evaporation process and should prove a valuable guide in searching for ways to minimize evaporation. Since an appreciable portion of the water supposedly used by a crop may be actually lost by evaporation, any decrease in evaporation will result in a lower rate of salination in the case of saline irrigation water, as well as conservation of limited water supplies.

Root Activity as Influenced by Moisture. At Tempe, Arizona, controlled experiments on uptake of water were conducted in the laboratory. Relative root activity measurements were made on sorghum plants that were subjected to higher moisture stresses than those ordinarily encountered in an irrigated field of this area. The technique involved the determination of radioactive phosphorus-32 in the plant leaf after the radiotracer had been injected into the soil

at varying distances from the plant. The data show that the rate of root growth is about 1 to 1.5 inches per day and the root extension is 30 inches laterally and at least 60 inches vertically from the plant row. Relative root activity distribution patterns were similar for all the irrigation levels investigated. Approximately 90 percent of the root activity is in the 10-inch lateral and 36-inch vertical distances from the plant. The relative root activity distribution is related closely to the moisture depletion patterns in the surface three feet as measured with the neutron moisture probe. It is thus evident that nutrient and water absorption for this crop occur concurrently and to a large extent above the 3-foot depth.

B. Determination of plant-soil-meteorological interactions involved in the movement of water in plants and the exchange of water, heat, and carbon dioxide between plants and the atmosphere

Influence of Radiation Distribution Within the Crop Canopy. At Ithaca, New York, the physical relationships that govern the intensity and quality of radiation distribution within the crop canopy have been well established. Within the action spectrum for photosynthesis (solar radiation between 0.3 and 0.7) it has been found that Beer's Law is applicable. This is also true of the near infrared portion of the solar spectrum (0.7 to 3.0). From this relationship, it is suggested that in further work on photosynthesis efficiency the crop community be characterized by an absorption coefficient as a function of depth of plant cover to replace "leaf area index."

At Florence, South Carolina, leaf area, leaf weights, and total dry matter production of tobacco were studied at various nitrogen fertilizer rates and at several plant populations. Mean leaf area per plant increased with plant spacing and nitrogen fertilizer treatment. Leaf weights per plant and per acre showed trends similar to those of leaf area per plant. The greatest increase in leaf nitrogen content preceded the greatest increase in leaf area.

Studies of photosynthesis and transpiration rates in a corn field under bright sunlight at Ithaca, New York, indicate that increasing wind increases photosynthesis rate, but does not affect transpiration rate. Evidently, photosynthesis is governed by the supply of carbon dioxide brought to the leaves by the wind movement. On the other hand, transpiration is governed by the energy available, and is not influenced by the rate at which the water vapor can be removed from the leaves. This means an increased efficiency of water use with increasing wind, or in other words, a higher production of dry matter per unit of water lost by transpiration.

Influence of Radiant Energy and Vapor Pressure on Transpiration. In the controlled-climate growth room at Watkinsville, Georgia, radiant energy, vapor pressure deficits, plant size, and age of plant accounted for 86 percent of the variation in transpiration of kidney beans. This defines for this crop the parameters in which modifications are possible. The stomata and their guard cells were studied, particularly in relation to transpiration. Stomatal opening of sorghum plants increased as light intensity and humidity increased, but there was no direct relation between stomatal opening and transpiration. Increased soil moisture tension above 0.15 atmosphere reduced transpiration, and tensions above 4 to 5 atmospheres reduced stomatal openings in sorghum plants.

Influence of Transpiration on Leaf Temperature and Turgidity. A convenient field instrument using thermistors to measure leaf temperatures was developed in Illinois. Initial studies indicate that corn leaves in sunlight were 0.5°C. cooler than the ambient air, while lower green leaves, in the shade, were as much as 6.5°C. warmer than the air. The work appears to indicate that transpiration has a cooling effect on plant leaves and thus may be necessary for plant survival.

At Weslaco, Texas, one year's data on the use of the relative turgidity technique indicate that the method can readily be used as a basis for determining when to irrigate cotton. Excellent control of the timing of irrigation applications was obtained based on relative turgidity measurements made on cotton leaves. The individual components of the crop environment (soil moisture, ambient temperature, and vapor pressure deficit of the air) influenced the internal water balance of the cotton plant during all stages of plant development. Soil moisture and ambient temperature accounted for 84 percent of the variation in relative turgidity.

In studies of plant-water relations conducted at Ithaca, New York, it was found that the relative turgor of the plant follows a diurnal cycle, the amplitude of which is governed by soil moisture and evaporative conditions. The sequence of conditions involved in drouth status of a plant is: First, there is loss of turgor; second, loss in turgor somehow hampers the photosynthesis process; and finally, transpiration is decreased.

Influence of Field Location and Plant Population on Microclimatic Factors. At Bushland, Texas, net radiation measurements made over an isolated irrigated grain sorghum field showed that during years of normal weather, the energy equivalent of the evapotranspiration ranged from 109 to 120 percent of the net radiation. As compared to a non-cropped field, evaporation from black and white atmometers averaged 7 and 11 percent less, 600 and 50 feet, respectively, inside the upwind edge of the field. Both these observations support the conclusion that considerable energy for evapotranspiration was supplied to the field by advection.

At Manhattan, Kansas, measurements of net radiation on sorghum plots having two row widths (20 and 40 inches) and two plant populations (60 and 480 sq. in. per plant) showed that for each row width when the plant population was high (60 sq. in. per plant) the crop plants themselves absorbed 93 cal./cm^2/day more energy than when the plant population was low (480 sq. in. per plant). On the other hand, the difference in energy absorbed by the plant under high versus low plant population, was compensated by the amount of energy absorbed by the soil.

Influence of Soil Moisture Regime on Evapotranspiration of Cotton. In studies at Weslaco, Texas, evapotranspiration rates of cotton were influenced by the amount of available moisture in the profile. Evapotranspiration rates were highest during the blooming and fruiting stages of growth but leveled off during the boll development period. If the cotton plant had sufficient moisture during the early bloom stage, yields were the same on plots irrigated at 50 and 25 percent available moisture.

Influence of Root Temperature on Transpiration. The effect of low root temperature and atmospheric saturation deficit on the transpiration of four alfalfa varieties was investigated in four controlled environmental experiments at Tempe, Arizona. These experiments emphasize the fact that wilting, which occurs when absorption is less than transpiration, depends on root temperature, concurrent transpiration rate, and the duration of the imbalance between the two processes. The transpiration rate occurring when the root temperature was at 5°C for four hours was depressed 70 percent as compared to the control (28°C). Transpiration rates at root temperature of 10°C were 20 percent less than the control.

C. Development of soil and crop management practices for maximum energy conversion

Plastic Mulches and Barriers. At Thorsby, Alabama, black plastic mulch over the drill row and clear plastic fences four-feet high at intervals in the field raised soil temperatures, increased the early growth of cotton, hastened maturity, and increased total yields. Topping well-fertilized, irrigated cotton plants at either 36, 42, or 48 inches high and pruning side branches hastened maturity, increased yields, and improved the quality of lint. Benefits obtained from this treatment were associated with microclimatic changes in the cotton.

Evaporation Control Materials. Hexadecanol, a straight-chain alcohol, is known to form a film on a water surface, such as a pond, and to reduce evaporation. It has been suggested that hexadecanol might form a similar film on the evaporating water surfaces within a plant or soil, and thus decrease evapotranspiration. Corn was grown

in the greenhouse in Illinois in containers which were sealed to prevent evaporation from the soil. In two experiments hexadecanol caused the plants to use less water, but only by causing the plants to grow less. The amount of water used per square centimeter of leaf was unchanged. In other greenhouse experiments hexadecanol additions did not reduce evaporation losses from clay or loam soils but did cause a significant decrease loss from sand. Much of the water movement above the water table in coarse sand is by vapor transfer, whereas most of the water movement in finer materials is by capillarity. Hexadecanol might be expected to interfere with vaporization within the soil more than with capillary movement.

Two comprehensive field experiments were conducted in Illinois in 1961 in which water use by corn was measured as influenced by broadcasting and banding additions of octa-hexadecanol to the soil. In one experiment the soil surface was completely plastic-covered and hence transpiration and drainage were the mechanisms of water loss. In the other experiment the soil was not covered and thus evaporation was an added component of water loss. No statistically significant difference in either water use or corn yield occurred as a result of octa-hexadecanol application. There was, however, a slight, but statistically significant, reduction in plant height associated with the octa-hexadecanol treatments. It was also found, in a laboratory experiment, that a synthetic resin did appreciably reduce soil evaporation; however, the application made the soil surface resistant to wetting.

The effect of octadecanol on the evapotranspiration rate of corn was studied in the greenhouse at Tempe, Arizona. Three rates (670, 3,350, and 16,750 pounds per acre) and two placement methods (thoroughly mixed and banded 8 cm below the surface) were used. During the first 18 days after seeding there was no significant effect upon evapotranspiration by the above chemicals. During the eight weeks of growth, two cycles of evapotranspiration showed no effect of octadecanol on lowering water loss as compared to control values. An early tendency to stunting at the 25-g dosage rate did not result in any significant difference in final dry weight between treated and control plants.

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AREA 12 NUTRITION OF ANIMALS AS AFFECTED BY PROPERTIES AND CHARACTERISTICS OF SOILS AND PLANTS

Problem. To improve nutrition of animals and man by discovering relationships among soils, plants and animals; to develop basic understanding of the synthesis and metabolism of nutritionally important substances in plants and animals; to determine the functions and pathways of transport of the various elements throughout the food chain from soil to plant to animal; to identify and characterize soil and climatic areas where the nutritional status of animals and man is affected adversely by qualities of the plants produced; to determine the relationships among soil properties, both natural and as modified by treatment, climatic factors, and the nutritional quality of plants as measured chemically or by feeding test animals, so as to enable farmers to select economic combinations of soil, crop and livestock management practices that will meet human nutrition needs.

USDA PROGRAM

The Department has a continuing long-term program involving soil scientists, biochemists and a plant physiologist at the U. S. Plant, Soil and Nutrition Laboratory, a U. S. D. A. laboratory located on the campus of Cornell University. Field and laboratory investigations directed toward understanding of the causes of animal nutrition problems occurring in a geographic pattern suggestive of soil or plant composition vectors are conducted and maps showing the distribution of soil related nutritional problems in livestock are prepared. Plants grown under specific conditions are analyzed for elements and compounds of nutritional significance and at times are fed to test animals to measure their effects on growth, reproduction and metabolic processes. The functions and interrelationships among the micronutrients in the food chain from soil to plant to animal are being determined, and studies of the chemical processes controlling the uptake of micronutrient element by plants are conducted. Work on the synthesis, transamination, and metabolism of amino acids and related substances in plants is underway, with special attention being given the sulfur compounds. An intensive study of the process of protein synthesis is being conducted with the current emphasis placed on the function and structure of the transfer ribonucleic acids.

Studies involving large animals are conducted through contracts with State Agricultural Experiment Stations. During the past year, contract research on molybdenum-copper-sulfur relationships in the nutrition of cattle has been conducted at the University of Nevada. A contract to investigate the effect of soil applications of selenium upon the incidence of myopathy in sheep was initiated at Oregon State University. Work on the causes of congenital malformations in livestock

is conducted in cooperation with the Animal Disease and Parasite Research Division at Logan, Utah.

The Federal scientific effort devoted to research in this area totals 12 professional man-years. Of this number, 1.8 are working to characterize soil and climatic areas where the nutritional status of animals and man is affected adversely by quality of plants produced; 3.4 are devoted to basic understanding of the synthesis and metabolism of nutritionally important substances in plants and animals; 1.8 to biological assays of plant material grown under different soil, geological and other environmental conditions to nutritional disorders in animals and man; and 5.0 to elaboration by plants of vitamins, amino acids, proteins, and other organic nutrient compounds required by animals. The Soil Conservation Service maintains a full time scientist at the Plant, Soil and Nutrition Laboratory for studies relating nutritional problems to specific kinds of soil.

RELATED PROGRAMS OF STATE EXPERIMENT STATIONS AND INDUSTRY

The State Experiment Stations in 1961 reported a total of 5 professional man-years divided among subheadings as follows: Characterize soil and climatic areas where the nutritional status of animals and man is affected adversely by quality of plants produced, 0.8; basic understanding of the synthesis and metabolism of nutritionally important substances in plants and animals, 2.1; biological assays of plant material grown under different soil, geological and other environmental conditions to nutritional disorders in animals and man, 1.1; and elaboration by plants of vitamins, amino acids, proteins, and other organic nutrient compounds required by animals, 1.0. Soil and climatic areas in which plants cause production problems in livestock are being characterized. The effect of soil fertility upon the synthesis of vitamins, proteins, carbohydrates, and other nutritionally important substances and the effect of soil conditions upon their metabolism in animals is being studied. Biological assay methods are being developed for the rapid determination of nutrient deficiencies or excesses and for identifying the soil, geological and other factors which contribute to the nutritional disorders of man and animals. Attention is being given to the properties of soils and plants which affect the synthesis of vitamins, amino acids, proteins, etc.

There is no research being conducted in this field by industry and other organizations.

REPORT OF PROGRESS FOR USDA AND COOPERATIVE PROGRAMS

A. Soil and plant composition as factors affecting the distribution of nutritional problems in livestock

Muscular dystrophy in livestock is distributed in a geographic pattern which suggests that soil and plant composition factors may be associated with the prevalence of this nutritional disease. Inasmuch as the addition of very small amounts of selenium to the ration has protected livestock from muscular dystrophy, attention has been focused upon the selenium content of livestock feeds in relation to this problem. Existing evidence does not clearly establish a relationship between the selenium content of the forages from various areas and the incidence of muscular dystrophy in livestock in the area. During the past year, samples of forages have been obtained from a number of farms and ranches where muscular dystrophy was known to be prevalent, and from similar properties where muscular dystrophy is not a problem. These farms and ranches are located in several different parts of the United States. These samples were collected in cooperation with the Animal Husbandry and Veterinary Science Departments of Oregon State University, University of Nevada, Cornell University and the Texas Agricultural Experiment Station. Currently, efforts are being directed toward development of methods for measuring the very small amounts of selenium present in these forage samples, and to comparisons of the selenium content of feeds from farms where muscular dystrophy has been prevalent with those where it has not occurred. The relationships between the content of selenium and other substances which might interfere with selenium metabolism will also be determined.

Along with this survey of the selenium content of forages, contract arrangements have been developed with Oregon State University to study the effect of addition of selenium to the soil upon the incidence of muscular dystrophy in sheep. In this study, selenium will be added to a part of a hayfield on a ranch which has had in the past a high incidence of muscular dystrophy. Hay from the treated portion of the field will be fed to ewes in comparison with hay from the untreated portion, and the incidence of muscular dystrophy in lambs born to these ewes will be determined.

In cooperation with Dr. Wayne Binns of the A. D. P. Division, efforts to clarify the cause of a congenital malformation in lambs have been continued. This malformation results in the birth of lambs with grossly deformed heads and is commonly termed, "monkey face." Since the problem was found only in a few geographic locations, it seemed at first that a mineral deficiency or toxicity in the forage of these areas might be involved. However, during the past two years, Dr. Binns has been able to produce the malformation by feeding the plant, "Veratrum Californicum," to ewes in the early stages of gestation.

The past year's work has, therefore, centered around determination of the specific components in Veratrum which are responsible for the malformation, and toward explanation of why Veratrum collected from different sites varies in its effect in producing the malformation.

In order to efficiently pursue this research, an attempt has been made to use the rat as a laboratory animal for assay of the toxic principle. A partial fractionation, designed to separate the alkaloids, was performed on a sample of Veratrum from a collection which had previously caused the malformation in sheep. The various fractions were fed to rats during the gestation period. In addition, several samples of the whole plant, from collections of varying toxicity to sheep, were fed to the rats under similar conditions. In this experiment, no interferences with gestation and the production of normal litters of rats was observed. This is in contrast to previous results at this laboratory using a similar assay technique. In a second experiment, it was found that a sample of Veratrum which, in 1959, had markedly interfered with gestation in the rats was no longer toxic at the levels previously fed (3% of the diet), but that a sample of more recent collection known to cause the malformation in sheep would interfere with gestation provided it was fed at a high level (10% of the diet). These results indicate that the toxic principle in Veratrum may be labile and decompose in stored samples, and that the level of the toxic principle in the plant may vary from season to season. Research designed to identify the toxic principle and account for its variations in the plants will be continued.

An intensive survey of the cobalt and copper concentrations in forages in New England was conducted in cooperation with the Soil Conservation Service. The objective of this study is to accurately define the soil areas in New England which produce forages containing insufficient cobalt to meet the requirements of livestock. Nearly 500 forage samples from about 250 different soil sites were collected and are currently being analyzed. From preliminary results, it appears that the major cobalt-deficient areas in New England will be located on Podzol soils developed on granitic glacial drift originating in the White Mountains of New Hampshire.

The molybdenum content of vegetation growing on poorly drained wet soils is often higher than that found in similar plants growing on the better drained and drier soils formed from the same parent material. A study of the effect of soil moisture level per se upon the uptake of micronutrients by plants might serve to explain variations in micronutrient contents of plants growing on different kinds of soils and in different seasons. For this reason, a greenhouse study has been conducted to measure the influence of soil moisture level upon the uptake of trace elements by alsike clover. Four soils with a known history of cobalt deficiency or molybdenum toxicity are included in the experiment. Alsike clover is grown at a high moisture level (water table at

7" depth) and a low moisture level (0.3 to 10 atmospheres suction) on each soil.

In the first two cuttings from this experiment, the molybdenum content of the plants was about twice as great on the wet treatments as on the dry treatments on all soils. These findings indicate that a high moisture level per se is a factor in the high molybdenum content found in vegetation growing on wet soils, and that improved drainage of these soils may help to reduce the molybdenum content of the forage.

In cooperation with the University of Georgia, Animal Husbandry Department, and the Southern Piedmont Conservation Experiment Station, a study of the effect of nitrogen fertilization upon the nutritional quality of Coastal Bermuda hay was conducted. Two lots of hay, one produced with an annual application of 100 lbs. N per acre, and one produced with an annual application of 675 lbs. N per acre, were fed to grade Angus steer calves for 140 days in a ration of hay, salt and cottonseed meal. The steers fed the hay produced with the high level of nitrogen gained 1.11 lbs. per day during this period, and consumed 12.5 lbs. of feed per pound of gain. The steers fed the hay produced at the low level of nitrogen fertilization gained .96 pound per day and consumed 14.1 lbs. of feed per pound of gain. Thus, under the conditions of this experiment, the hay produced at the high level of nitrogen fertilization was slightly superior to the hay produced at the low level of N fertilization.

Due to the recent findings that nitrates in feeds may interfere with the conversion of carotene to vitamin A in the animal, nitrates were determined on the hays and levels of carotene and vitamin A were determined on the blood of the experimental animals. The hay produced at the high nitrogen level contained an average of 1,100 parts per million of nitrate nitrogen, and that produced at the low level of nitrogen fertilization contained an average of 219 parts per million of nitrate nitrogen. The blood carotene tended to be higher and the blood vitamin A lower in the steers fed the high nitrogen hay than in the steers fed the low nitrogen hay. However, even in the steers fed the high nitrogen hay, the levels of vitamin A in the blood were above generally recognized critical minimums.

Following the termination of the experiment comparing the nutritional quality of Coastal Bermuda hay as affected by level of nitrogen fertilization, the steers used were pastured as one group for the summer at the Southern Piedmont Conservation Experiment Station. During this summer pasture period, these steers gained very little weight, even though other animals on similar pastures at the same station gained satisfactorily. The cause of the low summer gains on the experimental steers will be studied in future work on this project.

Many relationships of soils and soil management to the nutritional quality of plants are concerned with forage crops. Bioassay procedures, utilizing laboratory animals, are needed for the efficient study of some of these problems. Inasmuch as the rabbit will utilize diets containing a high percentage of forages, efforts have been directed toward the development of diets for rabbits to use as a base in the nutritional evaluation of forages.

The basal diet employed in these studies contained glucose, cellulose, corn oil, a purified protein, minerals, and vitamins. Several of the mineral requirements of the rabbit have been determined with this diet.

The results indicate that the rabbit requires 0.80% potassium, 0.30% sodium and 0.15% magnesium to achieve maximum performance. Attempts to produce a zinc deficiency have been unsuccessful. Therefore, it is concluded that the zinc requirement of the growing rabbit does not exceed the zinc supplied by the basal diet which contains 5-7 parts per million zinc.

B. Trace element interactions and functions in animal nutrition

Studies of the factors affecting the copper nutrition of animals--especially the copper-molybdenum-sulfate interrelationships--are continuing at this laboratory in cooperation with the Biochemistry Department of Cornell University. These studies are important for a better understanding of field problems involving the copper nutrition of grazing animals. Many of the observations with respect to Cu-Mo interrelationships and the effect of molybdenum on the copper status of the animal are conflicting. A level of molybdenum which has been found to be harmless under one set of conditions has produced toxic symptoms under another; or, a level of copper may be adequate at one location and the same level will not prevent a frank copper deficiency at another.

Experiments conducted several years ago at this laboratory demonstrated a beneficial effect of methionine on molybdenum toxicity in the animal. Studies in other laboratories confirmed this finding and added the information that inorganic sulfate was equally beneficial.

At about the same time that these observations were made using the rat as the experimental animal, studies by others with sheep showed that dietary sulfate accentuated a molybdenum-induced copper deficiency.

These completely contradictory findings with respect to the beneficial effect of sulfate in one instance and the detrimental effects in another were most puzzling. It was postulated that the apparent contradiction might be due to species difference--the ruminant vs. the monogastric animal.

Recent work at the laboratory has shown that the rat behaves like the sheep under certain conditions. The early work was planned to study molybdenum toxicity per se. Copper was included in all diets to meet adequately the copper requirement of the rat. The recent experiments were planned to study the effect of dietary molybdenum on copper-depleted animals, a condition more often encountered with field problems in which copper is a factor. A depletion period of about two weeks reduced the copper and iron stores of the weanling rats to a point of relatively severe anemia. When a low level of molybdenum (.001% Mo) was then incorporated into (-Cu) diets, a significant growth retardation occurred; when sulfate was also included with the molybdenum, the deleterious effect of this level of molybdenum was greatly accentuated. The animals fed this level of molybdenum gained approximately 2/3 as much as the animals on the minus Cu basal diet, while those fed Mo + SO_4 lost weight during the experimental period.

At the same time that these Cu-depleted animals were on experiment, another group of weanling rats (from the same breeding of the laboratory stock colony) was placed on Cu-adequate diets. Thus, these animals from a single breeding were studied under identical laboratory conditions, the only difference between the (+Cu) and the (-Cu) animals being their copper status. As in the earlier work with Cu-adequate diets, a higher level of dietary molybdenum (.08% Mo) resulted in about a fifty percent growth retardation. When sulfate was incorporated with molybdenum in the diets, the toxic effect of the molybdenum was eliminated. Sulfate was added at the same level to both the Cu-deficient and the Cu-adequate diets.

The results clearly demonstrated that sulfate fed with a toxic level of molybdenum to animals with a Cu-adequate status corrected the growth retarding effects of the molybdenum; and contrariwise, sulfate added to diets of Cu-depleted animals accentuated the toxic effects of dietary molybdenum. Eighty times as much molybdenum was needed to produce molybdenum toxicity in the instance of the Cu-adequate animals compared with that used with the Cu-deficient animals. While methionine exerted the same alleviating effects on molybdenum toxicity as in the earlier experiments (approximately 60% correction), Na_2SO_4 (sulfur equivalent to the methionine sulfur) completely corrected the toxic effects of molybdenum fed to Cu-adequate animals. The Mo + Cu + SO_4 treatment was no better than the Mo + SO_4 treatment--a further indication of the Cu-adequate status of these animals.

In the experiments with sheep, it was shown that sulfate must be present for molybdenum to exert an influence on the reduction of copper stores in the liver. A study is planned of the copper and molybdenum levels in the livers of rats (Cu-deficient and Cu-adequate), as affected by dietary sulfate.

Through contract arrangements with the University of Nevada, interactions of molybdenum with other elements have also been studied using beef cattle. The major experiment conducted during the past year was designed to measure the effect of level of protein and level of sulfate upon the toxicity of molybdenum. The basal ration was grass hay. Molybdenum (100 parts per million as inorganic molybdate), sulfate (.5% as sodium sulfate) and supplemental protein (6 lbs. alfalfa per day) were added to the basal diet, singly and in all combinations. Yearling heifers were maintained on these rations for ten months. Using weight gains as a criteria, the addition of sulfate to high molybdenum rations did not increase the toxic effects of the molybdenum.

This effect of sulfate is in contrast to that found in the experiment with copper-deficient rats described in this report, and is also in contrast to some of the results obtained by Australian workers. Biochemical measurements of the copper and sulfur status of the cattle will be conducted utilizing tissues collected during the feeding trial, in order to establish the reasons for this contrast.

In an auxiliary experiment at Nevada, animals grazing a normal low molybdenum irrigated pasture were treated daily with amounts of molybdenum estimated to be equivalent to 50 and 100 parts per million of molybdenum in the dry matter intake. The molybdenum was added as inorganic molybdate in gelatin capsules. The differences between control animals and molybdenum treated animals was much more pronounced under grazing conditions than in the dry lots. This indicates an increased toxicity of the same amount and chemical form of molybdenum to animals on fresh green forage as contrasted to animals on dry hay. This finding substantiates the belief of some ranchers that certain fields may be safely used as hay fields, but will result in molybdenosis when used for pasture.

During the past year, studies of the function of trace elements in the formation of bone have centered around the role of manganese in the formation of the organic matrix. Previous work at this laboratory has indicated that manganese deficiency in chicks results in a reduction in the mucopolysaccharide content of the epiphyseal cartilage of certain bones. The mucopolysaccharides that contain galactosamine are the most markedly reduced in these cartilages.

These findings offer a possible biochemical explanation for the bone abnormalities which occur in manganese-deficient chicks. Recent experiments have been concerned with the specificity of the manganese effect upon cartilage mucopolysaccharides. It has been established that a reduced food intake will not give rise to the reduction in mucopolysaccharides observed in manganese-deficient chicks. Experiments with graded levels of dietary manganese demonstrated a close relationship between manganese intake and the mucopolysaccharide content of the epiphyseal cartilage.

In chicks suffering from rickets (Ca deficiency) an increased mucopolysaccharide content is observed even at a low level of manganese intake. Increasing the manganese level to adequate amounts will bring about further increases in mucopolysaccharides in the cartilages. These studies will be continued looking toward clarification of the biochemical functions of manganese in bone formation.

The trace element content of a number of tissues from sheep is being determined in support of the research of Dr. Binns of the A.D.P. Division. The objective of this research is to determine whether or not various trace elements are accumulated in specific tissues, as an aid to the diagnosis of problems of mineral deficiency and toxicity.

C. Biosynthesis of amino acids, peptides and proteins

Studies of the intermediate chemical processes in the biosynthesis of proteins have been continued in cooperation with the Department of Biochemistry of Cornell University. The work has been centered on investigations of the nature of the soluble ribonucleic acids (RNAs) that transfer activated free amino acids to the "template" where protein synthesis takes place. A major objective of this work was attained during the year with the separation of three of the twenty amino acid specific yeast ribonucleic acids in form sufficiently pure for studies of their structure, and free of activity for the transfer of any other amino acid. The purified RNAs obtained are those which transfer alanine, tyrosine and valine. Structural studies have been initiated on these three ribonucleic acids. They are known to consist of long chains of four or five different nucleotide units and the structure problem is initially one of determining the number and sequence of units along the chain. The chains can be broken down to the individual nucleotide units by hydrolysis with KOH. Analyses of the nucleotides obtained in this way indicate that the alanine ribonucleic acid, as compared with the other two, has a very low content of adenylic acid and a high content of guanylic acid. The valine and tyrosine ribonucleic acids differ little in nucleotide composition. The RNA chains may be broken down to somewhat larger fragments called oligonucleotides by the action of the enzyme pancreatic ribonuclease. Identification of the oligonucleotides reveals the sequence of the individual nucleotides in short fractions of the RNA chain. Analyses of the compositions of pancreatic ribonuclease digests of the three ribonucleic acids, using a newly developed method of chromatography on DEAE-Sephadex, has established that they differ greatly in nucleotide sequence. Hardly a single oligonucleotide fragment is found to the same extent in pancreatic ribonuclease digests of the three RNAs. It is concluded that the three ribonucleic acids differ greatly in structure.

A simple method for the preparation of the amino acid-specific ribonucleic acids from mammalian liver was developed. This procedure, when used with beef or hog liver, should make the mammalian ribonucleic acids readily available and will facilitate studies of species differences in the ribonucleic acids.

During recent years, this laboratory has been successful in isolating and identifying a series of heretofore little known nitrogen compounds from plants. Several of these compounds are dipeptides in which the gamma carboxyl group of glutamic acid is involved in the peptide linkage. In some plant tissues, these γ-glutamyl dipeptides contain an important part of the total plant nitrogen. For this reason, knowledge of the identity of these compounds, their mode of formation, and their function in the plant needs to be explored in order to establish their significance in nitrogen metabolism, nutrition, and their relationship to toxic substances.

During the past year, three additional γ-glutamyl dipeptides have been isolated in crystalline form and their identity conclusively proven by comparison with synthetic dipeptides. One of these dipeptides (γ-glutamyl β-alanine) was isolated from iris bulbs. This peptide is very similar structurally to the "lathyrus factor" - the toxic principal of sweet peas. Possibly they are interconverted in the plant. γ-Glutamyl β-alanine has not previously been reported to occur naturally. β-Alanine was also isolated out of this tissue and compared with authentic material. Although β-alanine is widely reported in plants, this is the first time it has been isolated from a higher plant.

Soybean seeds were the source of the two other isolated dipeptides. These compounds have been shown to be γ-L-glutamyl-L-tyrosine and γ-L-glutamyl-L-phenylalanine. The identity was conclusively proven by comparison with synthesized dipeptides. The tyrosine dipeptide has not previously been reported to exist in plants although the phenylalanine peptide has been isolated from onion bulbs.

It is noteworthy that there was about 500 times as much β-alanine in the dipeptide form than unbound in the iris tissue. An analogous situation is found in soybeans where there was twenty-seven times as much tyrosine and seven times as much phenylalanine in the dipeptide form as in the free form.

In addition, two other γ-glutamyl dipeptides have been isolated from kidney bean seeds. These are probably γ-glutamyl leucine and γ-glutamyl methionine.

In an effort to learn something about the biosynthesis of the γ-glutamyl dipeptides, a search was made for an enzyme called glutathionase or transpeptidase. This enzyme is known to occur in animals and is presumably responsible for the degradation of glutathione. The enzyme transfers the γ-glutamyl group of glutathione to an amino acid to produce a dipeptide. Although transpeptidase had not been shown to occur in plants, it was readily demonstrated in a number of legume tissues. The enzyme was purified from kidney bean fruits and extensively studied. It was clearly demonstrated that the enzyme synthesizes γ-glutamyl dipeptides. It is probably responsible for the biosynthesis of the γ-glutamyl peptides of methylcysteine, methionine, leucine, phenylalanine and tyrosine. The enzyme does not form γ-glutamyl β-amino-isobutyric acid nor γ-glutamyl β-alanine. The pathway of formation of the latter two dipeptides is not known. The plant transpeptidase is quite different from the animal enzyme with respect to (1) location within the cell, (2) specificity towards amino acid acceptors, (3) inhibition by various sulfonphtaleins, and (4) activation by magnesium ions.

The work on the biosynthesis of dipeptides was particularly aimed at the formation of γ-glutamyl-methylcysteine in kidney bean seeds where it comprises nearly half of the non-protein nitrogen. Methylcysteine is of considerable interest because it is a sulfur containing amino acid. The essential sulfur containing amino acids are frequently the limiting amino acids in the utilization of plant proteins by humans and animals.

Although the sulfoxide of methylcysteine has been known for several years to be a prominent constituent of plants of the mustard family, methylcysteine has not been reported in these plants. Indirect evidence was obtained that methylcysteine also is present in these species. Intact crucifer tissues rapidly oxidize methylcysteine to its sulfoxide. This process is apparently enzymatic since heating at 100° for one minute abolishes the oxidation. The enzyme system is quite labile as evidenced by its inactivation by freezing, chloroform treatment, and mechanical disruption of tissues. The lability of the enzyme has prevented the preparation of a cell-free system which will oxidize methylcysteine.

In order to facilitate studies of nitrogen and sulfur metabolism in green plants, attempts have been made to induce biochemical mutants in chlorella by ultra-violet radiation. One mutant which could not utilize nitrate, but could use nitrate or ammonia, has been shown to lack nitrate reductase.

The amino acid distribution in oat forage as affected by nitrogen and sulfur supply was determined in support of the research on sulfur fertilization conducted by the Southeast Branch, SWC Division. The content of sulfur amino acids in oat forage was, in general, proportional to the total protein content.

D. Chemistry of micronutrients in soils

Studies conducted in cooperation with the Soil Conservation Service have served to establish the effects of weathering and soil genesis upon the distribution and availability of cobalt in the soils of Eastern United States. Two major processes tend to control cobalt distribution in soil profiles. The first process is downward movement of cobalt in the soil profiles through the leaching action of downward moving water. This downward movement is evidenced by the fact that in weathered soils the maximum concentration of total cobalt in the soil is generally in the B horizon.

The second process involved is an upward movement of cobalt, due to the fact that plants take up cobalt from various depths in the profile and deposit it on the surface with the plant residues. The existence of this process is revealed when samples of soil from various depths in the profile are extracted with dithionite or with 2.5% acetic acid, and the amount of cobalt extracted is determined.

The cobalt extracted by dithionite or 2.5% acetic acid is the most soluble and chemically reactive fraction of the total soil cobalt. This fraction can be considered to represent the circulating or "free" part of the cobalt. Where the maximum concentration of circulating cobalt is found at a higher level in the soil profile than the maximum concentration of total cobalt, the process of upward movement through the plant is keeping pace with downward movement through the soil, and the supply of available cobalt in surface horizons is being maintained. Where the maximum concentration of circulating cobalt is found deep in the profile, below the maximum of total cobalt, downward movement and loss from the soil is the dominant process, and ultimate development of a cobalt-deficient soil will result.

Measurements of the cobalt content of plants are in accord with this theory. In Gray-Brown and Red-Yellow Podzolic soils, the maximum concentration of dithionite or acetic acid soluble cobalt is found in the surface horizons, either the A_1 or the A_2. These soils almost always support vegetation containing adequate amounts of cobalt for grazing animals. In Podzols and Humus Ground Water Podzol soils, the maximum concentration of dithionite extractable cobalt is found below the maximum concentration of total cobalt. The cobalt content of the vegetation on these soils is frequently less than is needed to meet the requirements of grazing animals.

Investigations of the nature of the reaction between soluble cobalt and the solid particles in soils have been continued. An understanding of these reactions is required in order to develop efficient procedures for using cobaltized fertilizers to correct cobalt deficiencies in grazing animals. The work of the past year has been focused upon role of clay minerals, organic matter, and iron

coatings in the processes through which soluble cobalt is immobilized in the soil.

It was concluded from previous work that the sites of the reaction of cobalt with silicate clays are concentrated in zones around defects in the crystalline structure of the clay. These defects in crystalline structure apparently can result from weathering of the mineral surfaces or from laboratory treatments of the clay. The weathered nature of the soil surfaces is likely to have a greater influence on the reaction of a soil with soluble cobalt than does the average mineralogical composition of the soil. The iron coatings on the surfaces of the soil particles are involved in the reaction of these particles with cobalt. This is shown by the fact that removal of the iron coatings from a group of soils brought about changes in the reactivity of some of these soils with cobalt. A search for a method for removing heavy metal-organic matter complexes from soil has not, up to the present, been successful. Techniques based on destruction of the organic fraction with hydrogen peroxide have been found to dissolve cobalt from sources other than organically bound forms in the soil.

As another part of the continuing research program on the chemistry of trace elements in soils at this laboratory, an extensive review of the literature in this area is underway. This review covers copper, cobalt, zinc, iron, manganese, molybdenum and boron. A card system that will permit rapid survey of existing research in this field is being designed.

A requirement for cobalt by legumes in order to fix nitrogen has been established at other laboratories. An experiment has been conducted to determine whether or not some of the soils which produce vegetation with a very low concentration of cobalt can supply legumes with sufficient cobalt for normal plant growth. No definite responses to cobalt could be observed in alfalfa growing on any of the soils in the light chamber. The content of cobalt in the plant was very near the value found by other workers in soybeans suffering from insufficient cobalt. It would, therefore, appear that the level of available cobalt in these soils is marginal for legumes. Responses to cobalt on these soils might be found in the field under favorable growing conditions, but it is not likely that they would be large. It also appears that cobalt deficiency in grazing animals will be encountered before plant growth is restricted from lack of available cobalt.

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AREA 13 FERTILIZER TECHNOLOGY INVESTIGATIONS RESOURCES, PRODUCTION, AND IMPROVEMENT

Problem. The continued provision of adequate food and fiber for a growing population in a limited area necessitates eventual substitution of fertilizer for needed acres. The very modest rate of increase in consumer cost of fertilizers relative to the cost advances of other farm purchases, thus far held down by the use of technologic short cuts, cannot be thereby maintained much longer. The inescapable future rise in fertilizer cost will seriously hazard farm profits, unless fertilizers can be accurately fitted to crop requirements, so as to yield maximum returns on the dollar invested in them. Intensive research is needed for the protection of farm profits against this foreseeable hazard. Manufacturing techniques and use benefits have not been aligned for the purpose of discovery of the relationships between fertilizer character and performance in use. Several substances that carry the same nutrient element will generally differ in the responses imparted to crops and also in processing tractability in the manufacturing plant. There is need for systematic studies in search for those chemical and physical characteristics of fertilizer that control its behavior in the manufacturing plant and its performance in farm use. Precise information on this phase of the problem is necessary for the development (cooperatively with soil-management and crops units) of service requirements for important economic crops, which will provide specification goals for the guidance of the manufacturing technologist in his quest for effective fertilizers through process modification and new-product development. Millions of dollars have been spent on the development of fertilizer products that found no economic use. Improved procedures are sorely needed for the gathering and dissemination of accurate and up-to-date information on fertilizer resources and consumption trends--a matter of utmost importance to effective prosecution of timely technologic investigation.

USDA PROGRAM

The Department has a continuing long-term program involving inorganic and physical chemists, a soil scientist, a commodity analyst and a chemical engineer, engaged in basic chemical and physical studies and the application of known principles to the solution of fertilizer problems in the factory and in field distribution.

The Federal scientific effort devoted to research in this area totals 27 professional man-years with 10 in basic research and 17 in applied research. Of this number, 14.5 are devoted to materials development and refinement; 4.5 to mixed-fertilizer investigations; 4.5 to quality-control methods for marketed products; 1.0 to agricultural chemical additives; and 2.5 to consumption trends and use patterns.

RELATED PROGRAMS OF STATE EXPERIMENT STATIONS AND INDUSTRY

State Experiment Stations in 1961 reported a total of 13.6 professional man-years divided among subheadings as follows: Materials development and refinement, 8.4; mixed fertilizer investigations, 4.5; and agricultural chemical additives to fertilizers, 0.7. Many of the State stations are cooperating with USDA, the Tennessee Valley Authority and the fertilizer industry in evaluating new fertilizer materials. Limited investigations on liming materials and other acidity adjusters, as well as carriers of minor elements, are in progress at a few of the State Experiment Stations. Investigations are also being made on the use of coatings on fertilizer granules to control the rate of solution, and solid versus liquid formulations are being compared.

Industry and other organizations including research institutes and chemical companies, perhaps 150 or more, conduct research and development studies looking mainly to improvements in processing methods. Their results are generally kept confidential except those published in patent literature. Estimated annual expenditures are equivalent to approximately 600 professional man-years.

REPORT OF PROGRESS FOR USDA AND COOPERATIVE PROGRAMS

A. Materials development and refinement

Study on a spectrophotometric method for evaluating urea-formaldehyde products in mixed fertilizers with the use of chromotropic acid as the reagent was pursued far enough to show that this reagent, which performs very well indeed on urea-formaldehyde products alone, has little promise of general use for determining them in mixed fertilizers, because commercial mixtures generally contain substances of organic origin in variable and unpredictable amounts, which impart interfering colors to the test solution.

The quality of the nitrogen in commercial mixed fertilizers is under study in an experiment in progress. The nitrification characteristics of forty-odd specimens are being determined in a manner that permits an evaluation of the effect of particle size of the fertilizer. Some of the test materials typify commercial proposals for retarded fertilizer-soil reaction through the use of large granules of the nitrogen carrier. The tests will be completed during the coming summer.

Work on the analytical separation of ammonic, nitric and amidic forms of nitrogen with the use of ion-exchange resins was continued during the first half of the year with emphasis on procedure refinement with respect to capacity of available resins, characteristics of exchange columns and suitable concentrations of test solutions. A satisfactory technique was developed, and in an exploratory experiment

its performance was compared with that of currently-used procedures for determining these forms of nitrogen. The study will be resumed in early summer 1962.

Work on inhibitors of urea hydrolysis was continued on a limited scale in the laboratory with the object of determining the extent of urea hydrolysis occasioned by urease and bacteria native to eight soils. Nitrogen was evolved in variable amounts from soil slurries containing urea, when the soil was neutral to alkaline and the temperature was 40° C. Evolution in detectable amounts did not occur in the case of acid soils, or when the temperature was 30°. The largest observed evolution, were it continued at the same rate for five days, would amount to about 4 percent of the added urea. Further work is contemplated.

The systematical study of the pore structure of superphosphate and phosphate rock, and its relationship to the performance of these materials in use, was continued at a steady pace. Work thus far envisioned on the character of superphosphate showed that the volume of fine pores (diameter less than 0.06 micron) generally decreases from normal to triple to ammoniated superphosphate and often varies markedly, though as yet unpredictably, with particle size. Further work on superphosphate is not planned for the near future.

The possible exploitation of newly-discovered deposits of phosphate rock in Peru, which reportedly amount to 500 to 600 million tons of marketable rock, is a matter of considerable interest. Pore-volume measurements and acidulation tests, made on several specimens said to typify anticipated production, indicate that rock from this field is equally as reactive as rock from Tunis.

The use of calcination (800-900° C.) to up-grade phosphate rock and improve its acidulation characteristics has increased rapidly in the past year or two. A study begun this year is directed to the delineation of the changes in pore structure that occur during calcination. Examination of commercial calcines showed that the heat treatment, as practiced today, changes the pore structure in the direction of lowered reactivity. In the extreme case, for example, calcination at 900° C. reduced the surface area from 30 to 1 sq. m. per gram, the total pore volume by one-half and the fine-pore share of the pore volume (the component most influential on the reactivity) from 80 to 17 percent. Further work under way is concerned with a search for possible optimal calcination temperatures for rocks from different fields.

Work on the nutritive value of water-insoluble phosphates was not pursued this year, because key people were absent on outside assignments for long periods. Two short-term greenhouse experiments on other topics were conducted. One, made at the instance of the Crops

Division, was concerned with high-level fertilization of bluegrass with superphosphate on Evesboro loamy sand soil. Significant increases in response to phosphorus were observed up to 2,000 pounds of phosphoric oxide per acre.

In another experiment, urea and ammonium nitrate, respectively, were used as the sole nitrogen carrier in 1:1:1 liquid fertilizers applied in different amounts up to 150 pounds per acre, and according to different time schedules, to corn growing on Davidson silty loam soil in greenhouse culture. The stover yield and phosphorus uptake increased with the amount of fertilizer applied in all treatments and were significantly greater with ammonium nitrate than with urea.

The study concerned with causes for large differences between wet- and dry-sieving of certain limestones was continued with emphasis on the magnitude of the difference and its relationship to particle size and magnesium content. The results obtained on 30 selected specimens of agricultural limestone show that the difference between observations by the two sieving techniques (wet-sieving gives the lower figure) increases in nearly linear fashion with decrease in particle size and, in terms of the value found by dry-sieving, ranges from 7 percent for the 30-40 mesh size to 53 percent for the 200-270 mesh size. On the other hand, the difference declined with increase in magnesium content at an average rate of 0.005 percent per 1 percent of $MgCO_3$.

These results find application in a movement under way to standardize market specifications for agricultural limestone, which is prompted by wide demand for greater uniformity in State specifications. The American Society for Testing Materials, taking notice of the problem, set up a committee last year to deal with the problem. A laboratory representative serves this Committee on a consultant basis.

The greenhouse study on the liming quality and fertilizer value of flue dust from cement kilns was terminated and the results are being prepared for publication in 1962.

The work concerned with primary carriers of zinc, though retarded most of the year by lack of staff, has progressed to readiness for greenhouse tests on characterized glasses and minerals. A paper on "Properties and Uses of Micronutrient Glasses in Crop Production" was prepared jointly with workers in Auburn University and Clemson College for an American Chemical Society symposium in Chicago, September 1961.

Preparation of a comprehensive treatise on principles and practices in superphosphate manufacture was continued in cooperation with the Division of Chemical Development, Tennessee Valley Authority. Although two chapters still remain to be submitted to the joint committee, the task of editing the subject matter is well under way.

B. Mixed-fertilizer investigations

Preparation of test fertilizers and other materials for experimentation by persons outside the Division was continued in response to demand. During the 15 production weeks in the calendar year 1961, about 4 curies of phosphorus-32 was received and processed into 15 kinds of fertilizer containing in all 44 pounds of phosphoric oxide. These materials comprised 28 shipments to ten cooperators in the United States, four in Canada and one in Austria for use in studies on root absorption capacity under different fertility situations, phosphorus uptake, sugar-cane fertilization practice, tomato and carrot field experiments, and influence of soil temperature on phosphorus availability to growing barley, among other things. Miscellaneous preparations include several lots of glass beads labeled with iodine-131, sodium and lithium pyrophosphates, sodium acid pyrophosphate, and two orthophosphates of lithium.

The study on the influence of physical properties of ingredients on the behavior of fertilizer mixtures in granulation processes was continued with emphasis on the optimal particle-size of triple superphosphate and of potassium chloride. The results of an experimental study on the "Effect of Particle Size on the Granulation of Triple Superphosphate" were reported in a paper given in the Annual Meeting of the American Chemical Society, September 1961, which is expected to appear in print in early 1962. An invited paper on "Fundamental Principles of Fertilizer Agglomeration" was prepared for spring 1962 meeting of the American Institute of Chemical Engineers.

Attention to particle-size distributions of ingredients used in formulating mixed fertilizers was shifted from triple superphosphate to potassium chloride, which is available to the fertilizer trade in three fairly consistent finenesses--coarse, medium, and fine. The work is in progress. Exploratory trials showed that the desired size distributions of the blended ingredients (before granulation) can be reproduced within a fair degree of approximation, and granulation tests made to date indicate that nutrient uniformity in the product is markedly affected by the initial fineness of the potassium chloride.

Experimental studies were begun on the delineation of differences between granulative characteristics of multi-nutrient mixtures containing the chloride, sulfate and nitrate of potassium, respectively, and on the development of a laboratory technique for studying the controlling factors in slurry granulation. The latter type of process, which has found limited use in the fertilizer industry, accomplishes granule growth by coating small seed particles with a heavy slurry under suitable conditions, drying the resultant product, screening it, and retreating the undersize material. A laboratory technique that merits further study consists of spraying the slurry on a curtain of falling particles.

C. Quality-control methods for marketed products

Work concerned with the development of improved methods of sampling and analysis of fertilizers and other soil additaments, in cooperation, as the occasion demands, with the Association of Official Agricultural Chemists and other private associations, as well as with Federal and State government agencies was continued with emphasis on phosphorus and water in fertilizers and on the silicon content and quality evaluation of agricultural limestone.

In a collaborative study of analytical methods for phosphorus, two proposed procedures based upon quinolinium molybdate reagent were compared with the official volumetric molybdate procedure with the use of results obtained on six samples by nine laboratories and found to be suitable for determining phosphorus in fertilizers. In a related study concerned with bias of analytical methods, the forementioned procedures and three others were compared with the use of results obtained by eight laboratories on a standard sample of accurately-known phosphorus content. The biases shown by the departure of collaborator means for the different procedures ranged from -0.06 to +0.80, and the procedure with the largest indicated bias happened to be the official procedure most widely used at the present time. Further work on the procedures will be carried out the coming year.

A study of methods for determining water in fertilizers was begun late in the year. Since water content is not an item in the required guarantee, methods for its determination have not been developed to the point of adequacy for current requirements in quality control of marketed fertilizers. The study will be concerned with the suitability and precision of a number of procedures, both chemical and physical, for water determination, which hold promise of establishment as routine or referee methods.

Constituents other than calcium and magnesium in liming materials are attracting increased interest among control officials and agronomists. Promising methods for determining silicon in liming materials were discussed in a paper presented in the 1961 meeting of the Association of Official Agricultural Chemists, and the Association authorized a collaborative study of them to be made in 1962. Three methods will be applied to the determination of silicon in six selected liming materials by nine laboratories, and the results will be reported to the 1962 meeting.

The cooperative study on EDTA activity evaluation of limestone, conducted by several State Experiment Stations and the USDA, was continued. At the request of the committee in charge of the study, the Fertilizer Laboratory made a statistical analysis of the voluminous results obtained by the collaborators, in which several laboratory procedures were compared by reference to the capacity of the limestone

to change soil acidity as measured in incubation experiments. The EDTA procedures were found to give satisfactory indexes of limestone activity, but the correlation was not consistently better than that shown by percentage of calcium carbonate.

D. Agricultural chemical additives

The greenhouse study on the compatibility of the growth retardant, tributyl-2,4-dichlorobenzyl-phosphonium chloride (Phosfon), with common fertilizer salts was continued through the first half of the year. Davidson soil used in the earlier experiment with tomatoes was reseeded to pinto beans, in order to test for residual growth-regulating potency. Potency was found in year-old culture media that had been treated with 100 pounds of Phosfon per acre, though it was not noticeable with a 10-pound application.

E. Consumption trends and use patterns

The regular annual survey of consumption of commercial fertilizers in the United States and Territories was completed for the year ended June 30, 1960. Commercial fertilizers consumed during this period amounted to 24,877,415 tons comprising 15,649,622 tons of mixtures and 9,227,793 tons of materials, inclusive of 1,378,179 tons of secondary and trace nutrient materials. Consumption of both classes of fertilizers was slightly below the figures for 1959--mixtures, 2.6 percent, and materials (exclusive of secondary and trace nutrient group, which was 12.7 percent higher), 1.9 percent. Consumption of nitrogen amounted to 2,738,047 tons; available phosphorus pentoxide, 2,572,342 tons; and potassium oxide, 2,153,319 tons for a total of 7,463,714 tons, which is 0.6 percent higher than the figure for the preceding year. The average nutrient content of mixtures was: N, 6.50; available P_2O_5, 12.99; and K_2O, 12.06 percent, which lie in comparison with 6.22, 12.54, and 11.91 percent, respectively, for the preceding year.

The annual preliminary estimate of consumption of commercial fertilizers in the United States and Territories was made for the year ended June 30, 1961. In 1961 consumption increase exceeded the drop shown in 1960 by a very slight margin. Gains over 1959 are indicated in all categories except tonnage of mixtures.

Work concerned with sources and supplies of fertilizers was directed mainly to summaries of useful information on nitrogen-bearing liquids for technical and farm fertilizer uses. Agricultural Handbook No. 198, entitled: Liquid Nitrogen Fertilizers for Direct Application, published in September 1961, is in wide demand at home and abroad. A revised compilation of the "Physical and Chemical Characteristics of Commercial Nitrogen Solutions for Fertilizer Use," was published. The final tabulation showed 99 solutions (instead of 58 noted in the report last year) that are produced by 27 companies in the United States and

Canada, comprising 21 non-pressure solutions and 78 pressure solutions, of which 40 are ammonia-ammonium nitrate-water, 17 are ammonia-urea-water and 21 are ammonia-ammonium nitrate-urea-water.

"A Decade of Direct-Application Fertilizer Solutions" is the subject of an article prepared at the request of Solutions, the official publication of the National Fertilizer Solutions Association. During the year 1959-60, nitrogen solutions (exclusive of anhydrous ammonia) were used for direct application to the soil in all the States except Rhode Island and West Virginia. Consumption of nitrogen solutions that year amounted to 271,516 tons of nitrogen, of which 76,776 tons were in the form of aqua ammonia. Solutions accounted for about 16 percent of the nitrogen carried in fertilizers consumed for direct application, for about 3 percent of the available phosphorus so used, and for only 0.1 to 0.2 percent of the potassium.

Work on the development of the amounts of nitrogen, phosphorus, and potassium used on economic crops in 1959 was continued. Salient findings for the Corn-Belt, Lake, and Southeastern States were summarized in an invited article for Plant Food Review. Between 1954 and 1959 the acreage to hay and cropland pasture declined in all three regions. The tonnage of fertilizer also dropped about 14 percent, but the total amount of applied nutrients increased 8 percent. The average ratio of fertilized acreage to harvested acreage of soybeans changed little, though the harvested acreage and amount of applied nutrients increased substantially over the five-year period. The most marked increases in fertilized corn acreage occurred in the Lake States, where per acre application of nitrogen showed the largest increase (almost doubled). The acreage of harvested wheat in the Corn-Belt and Lake States was up by about 250,000 acres in 1959 over 1954, and the consumption of nutrients applied to this crop advanced about 20,000 tons.

Collection of information on international developments concerned with fertilizers was continued by systematic reviews of sundry reports of the U. S. Foreign Service and the Food and Agriculture organization of the United Nations, by perusal of notes in trade journals, and in incidental contacts with Government and private agencies, as well as with informed individuals. Notes on developments were summarized in SWC Special Report No. 103. Information on fertilizers was supplied to the Agency for International Development, the Organization for European Economic Cooperation, and 28 foreign visitors.

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AREA 14 SOIL AND WATER MANAGEMENT AND CONSERVATION FOR SPECIFIC CROPS

Problem. The importance of soil and water conservation in the nation's agriculture can hardly be overestimated. Without these natural resources there would be no agriculture - no crops - no food - no fibers--the nation's very existence is dependent on its soil and water resources. The development of improved tillage, crop residue management, fertilization, drainage and irrigation practices requires not only a knowledge of soil and climatic factors, but also widely varying moisture, temperature and nutrient requirements for establishment and growth of different crops.

Each crop and each physiographic area presents specific problems on soil and water management and conservation. For some crops the problem is excessive moisture at seeding. For other crops, adequate moisture must be provided at seeding. High soil temperatures are critical for some crops, whereas low soil temperatures are the major problem for other crops. For legumes, proper inoculation may be a problem. Consumptive use of water, water use efficiency and proper timing of moisture and fertilizer applications need further study for various crops. In studying these various factors, different crops are used as tools to measure soil and water research responses.

USDA PROGRAM

The Soil and Water Conservation Research Division has a continuing program doing basic and applied research and employing 17 disciplines to increase knowledge in all phases of soil and water management and watershed engineering. The total professional man-years involves 416 trained and specialized workers. These man-years have been accounted for in the reports for Areas 1 to 13.

RELATED PROGRAMS OF STATE EXPERIMENT STATIONS AND INDUSTRY

State Experiment Stations in 1961 reported a total of 20.3 professional man-years divided among subheadings as follows: grains, 4.0; forage, feeds and seeds, 6.1; cotton, 1.2; sugar plants, 0.2; tobacco, 1.0; citrus and subtropical fruit, 2.6; potatoes, 0.6; vegetables, 3.6; and oilseeds and peanuts, 1.0. The professional man-years for much of the research on specific crops at the State Stations is reported in other areas of this report.

REPORT OF PROGRESS FOR USDA AND COOPERATING PROGRAMS

Sugar Beets

Forty-eight commercial sugar beet fields with promise of high yields were studied in 1961. These fields were widely scattered in Western United States.

The seasonal nutritional status of sugar beet plants grown on these productive farms were judged with proposed critical level standards. Of the forty-eight fields examined not more than three could have been adversely affected by lack of available nitrogen. Phosphorus and potassium were present in adequate supply when tested against critical levels. The conclusion from this study is that generally, high producing farms are either in excellent condition nutritionally, throughout the entire Western area or that critical levels are not a suitable and sensitive measure of nutritional status of sugar beet plants.

The application of quantity and quality factors and nitrogen: potassium ratios, which were standardized by nutrient culture studies were made against beets grown on productive farms. These studies indicate that standards set-up as a result of the nutrient-culture studies are not adequate to test field-grown beets or that most high producing fields are out of balance with respect to nitrogen and potassium.

These observations made it imperative that additional studies be made to clarify the basis for appraising the nutritional status of sugar beet plants.

At Brawley, California, an unfertilized sugar beet crop was grown during the 1960-61 season to measure residual nitrogen supplies in the soil of the experimental plots. The data collected indicated the entire experimental area to be uniformily low in nitrogen. It was concluded that there was no residual nitrogen supplies in the areas of any of the previous treatments.

Sugar beets were planted at Grand Junction, Colorado, at an early date in 1961. Yields of roots and tons of sugar were greater on the 6-year rotation than on the 3-year rotation, while sugar percent of the 6-year rotation was slightly reduced. Trends noted from fertilizer treatments in previous years continued in the 1961 yield results. Without fertilizers, yields were extremely low. The application of nitrogen resulted in only a slightly greater root yield. With the drop in percent sugar from this treatment, yields of sugar were actually no more than from the non-fertilized treatment.

The phosphate treatment resulted in yields averaging 12 tons per acre on the 3-year rotation and 22 tons on the 6-year rotation. Applying nitrogen with the phosphorus gave added increases in yield although some of these N treatments were more effective than others. Nitrogen affected root yields and percent sugar principally at the higher rates of application. Also, yields were not as high as other NP treatments on plots where N had been reapplied again in the 1961 season.

No apparent increase in root yield or percent sugar was noted when potash was applied with N and P. Manure increased plot yield of beets above non-fertilized plots, but when compared to a similar NPK treatment, yields were nearly equal.

At Huntley, Montana, leaf area index of sugar beets was found to be greatly affected by nitrogen fertilization but practically unaffected by spacing of beets in the row except early in the season. The spacings used were 6, 12, and 18 inches between plants in the row with rows 24 inches apart. Conversely, leaf area per plant was greatly affected by both nitrogen fertilizer, applied in April and in mid-August, and by plant spacing. Beet yields were increased only slightly by nitrogen fertilizer (1.5 T/A). The 6, 12, and 18 inch spacings yielded 17.1, 18.0, and 20.0 tons respectively. Sugar content and thin juice purity were both lowered by nitrogen fertilizers. Both leaf area index and leaf area per beet were found to significantly, negatively correlate with sugar content and thin juice purity. The correlation coefficients were in the range of about .55 to .75. Leaf area and leaf area index were found to be only generally associated with root growth. The relationship does not appear to be a causative one. Frequent showers and/or reduced solar radiation appeared to reduce effective leaf area.

Land forming in the Red River Valley is more a water spreading practice than a surface drainage practice. Soil moisture is more uniform on land formed plots with consequent better operation of field machinery. Seeding is possible earlier in the spring and tillage is possible sooner after rains. While sugar beet yields on well drained parts of the field may not be increased, land forming increases average yields by both increasing yields on former depressed wet areas in the field and permitting more timely farming of the remaining areas in the field.

Experiments on deep plowing and subsoiling of large field plots and farm fields indicate that the soil can be effectively and economically reclaimed by the deep plowing treatments alone. Infiltration rates and penetration of water and roots was greatly improved. Salinity and exchangeable sodium content were reduced to noncritical levels within 2 crop years. Crop production on the deep-plowed Sebree (slick spot) soils was greatly increased; yields of alfalfa hay, barley, wheat, sugar beets, and corn were increased four to five times in comparison to the yields on the unplowed soils.

Sugar Cane

A revolutionary type of drainage system for the sugar cane in Louisiana was formed on an area to precision grades of .08 and .05 feet per 100 feet in 1957. The entire area had a side fall of .05 feet per 100 feet. In 1958 it was fallow and was planted to sugar cane in the fall. The first sugar cane crop was harvested in 1959. Each row drains into a field drain and is crossed by the implements.

Field observations in 1960 and 1961 showed that the contemplated cultivating and harvesting hazards were minor. Cultivators, harvesters, and canewagons crossed the field drains without any difficulty. When rear-mounted cultivators are lifted out of the ground they leave

depressions approximately 3 feet up the row from the field drain. To date, tractor drivers have not been able to comprehend the need for controlling the depth of their cultivators when they lift them from the ground. This area had an average yield of 31.6 field tons per acre. This was the second stubble cane. There were no second stubble cane yield data of the same variety available for comparison.

The benefit of this type of drainage system is primarily the ease of maintenance and the amount of land (4.5%) placed in cultivation that had been used in ditches. This is especially important at the present time since increased sugar production is so important because of the Cuban situation.

Two areas on the DeVall and Kayo properties were harvested in December after the heavy rains. On these two areas the tractor and cane carts did not mire as deeply as on the conventionally drained areas. Little difficulty was encountered in crossing the ditches. The Kayo property used three carts behind their larger tractors.

This system has been under observation for three years. It is gratifying the way the practice is being accepted by the sugar industry. The benefits of this system has not been primarily on crop response, but in reducing maintenance costs of drainage and lessening the amount of land in ditches. A conference was scheduled with SCS in February, 1962, to review this practice and set up some tentative specifications for the work, such as ditch and land slopes.

Land forming in the sugar cane lands of Louisiana have greatly improved water management and enabled more efficient use of crop production equipment. Row grade and length studies are underway for these soils.

Experiments on plowing 14 to 18 inches deep at Baton Rouge, Louisiana, indicated that sugar cane responded to deep plowing only in years of sparse seasonal precipitation.

Tobacco

The use of irrigation to insure production of adequate yields of flue-cured tobacco is a common practice among farmers in the flue-cured tobacco belt. It has been shown that yields can be increased by irrigation, even in years of very moderate drought occurrence. However, chemical analysis of irrigated tobacco has shown some quality factors to be adversely affected. Evidence from previous research indicates the possibility of compensating benefits from the use of correct fertility levels, particularly nitrogen.

Results obtained from 1961 experiments show that tobacco production was not significantly increased by irrigation. However, nitrogen levels of 50, 70 and 110 pounds per acre gave highly significant yield increases when compared to the low rate of 30 pounds per acre. The higher rates of nitrogen were also responsible for highly significant increases in the acre value of the crop, although 110 pounds of nitrogen per acre caused a decrease in quality as reflected by unit price. While not statistically significant, trends for yields, and value and price per pound were observed to be increased by irrigation.

The maintenance of soil moisture levels within the root zone not in excess of 0.8 atmosphere of soil moisture tension provides adequate water for leaf production.

Irrigation and excessive soil moistures tend to lower nicotine content of the leaf and raise sugar content. This characteristic has caused an attitude of reluctance among tobacco processors toward accepting irrigated tobacco. Nitrogen, on the other hand, tends to increase nicotine and reduce dextrose. The research indicates that fertility practices in association with irrigation may be developed to the extent of producing generally analytically acceptable tobacco under irrigation.

The experimental data of 1961 indicate a possibility that much of the nitrogen applied at transplanting may have been leached beyond accessibility of roots by heavy rain immediately following. Since part of the total nitrogen and potassium were applied as later side-dressing, the effectiveness of total application of nitrogen may have been reduced by the early leaching.

Nitrogen applications of 110 pounds per acre reduced unit leaf value in 1961.

Flooding following irrigation affected yield and quality of leaf but not to any great extent. It must be noted that the soil on which the experiment was conducted is basically well drained, permitting the downward movement of excessive moisture within a relatively short time.

Irrigation tends to encourage early ripening of leaf, while nitrogen tends to delay ripening.

In Virginia, a study is in progress on land forming as a basis for improved tobacco cultural system. A long-range field experiment was installed in the western portion of Piedmont Virginia (Franklin County) to test the application of land-forming procedures for overcoming or minimizing the obstacles caused by most of the currently employed soil erosion control practices used in flue-cured tobacco production. Because of tobacco's sensitivity to the condition and depth of topsoil, the land-forming procedures used involved three methods of topsoil

manipulation. One treatment was formed without special consideration for maintaining a suitable layer of topsoil over all areas. In the second treatment, the topsoil was stockpiled, the subsoil formed to prescribed grade, and the topsoil respread over the surface. In the third treatment, the land was formed to near grade and topsoil was brought in from a borrow area to complete the filling to grade and provide a minimum topsoil cover of 0.3 feet over the entire test area.

Volumes of soil moved in forming the treatment areas ranged from 300 cu.yd/ac. for the more gradual slopes to more than 500 cu.yd./ac. on the steeper slopes. Costs of forming operations were a function of the forming procedure used for the treatment--18¢/cu.yd. for the mixed soil treatment, 26¢/cu.yd. for the treatment in which soil was added, and 52¢/cu.yd. for the stockpiled topsoil treatment.

The effect of soil manipulation was reflected in soil density where the deeper fill areas had a considerably higher density than that of the deeper cut areas.

Soil fertility measurements indicate that the soil, Cecil fine sandy loam, has a low pH, is low in CaO and organic matter, and contains an average amount of MgO, P_2O_5 and K_2O.

Each treatment was divided into two 60-ft. wide, parallel strips. Beginning with the 1962 crop season, one strip from each treatment will be planted to tobacco, while the alternate strip will be in a fescue sod.

Tobacco yields are considered the summation of climatic variations and/or the effects of environment. In order to understand the specific effects of these factors on tobacco yield, the optimum course of plant growth and development is required. Although the economic yield is not necessarily the maximum biological yield, they are closely related as the factors involved in attaining the two yields are essentially the same.

An experiment with Burley tobacco (Ky. 16 and Ky. 16 Mammoth) at Blacksburg and one with flue-cured tobacco at Chatham in 1961 gave the following results.

Exploratory investigations with Ky. 16 and Ky. 16 Mammoth varieties of Burley tobacco using different plant spacings to evaluate leaf area per acre and dry matter production were very fruitful.

A high degree of association was found to exist between green leaf weights and leaf area as the correlation coefficient was 0.9361.

Leaf area index (LAI) for the two tobacco varieties was also determined and found to range from a factor of 2 to 10 depending on population density.

The use of heating cables in the early part of the growing season stimulated growth, however, yields from the Ky. 16 could not justify their use. For the Mammoth variety, where a longer season is required for the plant to flower, heating cables appeared to be more beneficial.

Attempts to determine the influence of plant geometry on leaf shading with temperature measurements were not successful.

Correlations of green leaf weights with cured leaf weights were less consistent and were characterized by lower r values.

A black plastic film used as a mulch with early planting at Chatham was beneficial in maintaining a high initial stand as well as providing a yield increase of almost 200 pounds per acre.

Additional research is needed to substantiate the findings of the 1961 season as none of the field plots were in a replicated experiment.

At Florence, South Carolina, leaf area, leaf weights, and total dry matter production of tobacco were studied at various nitrogen fertilizer rates and at several plant populations. Mean leaf area per plant increased with plant spacing and nitrogen fertilizer treatment. Leaf weights per plant and per acre showed trends similar to those of leaf area per plant. The greatest increase in leaf nitrogen content preceded the greatest increase in leaf area.

At Raleigh, North Carolina, use of a transpiration suppressant (Wilt-Pruf) increased afternoon leaf temperature some 3°F. on the average on tobacco, but during periods of sunshine the temperature difference was considerably greater. Measurements in the field and in the growth chamber failed to show important differences in leaf temperatures from plants grown at different water table levels.

Grain

At Ithaca, New York, the physical relationships that govern the intensity and quality of radiation distribution within the crop canopy have been well established. Within the action spectrum for photosynthesis (solar radiation between 0.3 and 0.7) it has been found that Beer's Law is applicable. This is also true of the near infrared portion of the solar spectrum (0.7 to 3.0). From this relationship, it is suggested that in further work on photosynthesis efficiency the crop community be characterized by an absorption coefficient as a function of depth of plant cover to replace "leaf area index."

Studies of photosynthesis and transpiration rates in a corn field under bright sunlight at Ithaca, New York, indicate that increasing wind increases photosynthesis rate, but does not affect transpiration rate. Evidently, photosynthesis is governed by the supply of carbon dioxide brought to the leaves by the wind movement. On the other hand,

transpiration is governed by the energy available, and is not influenced by the rate at which the water vapor can be removed from the leaves. This means an increased efficiency of water use with increasing wind, or in other words, a higher production of dry matter per unit of water lost by transpiration.

A convenient field instrument using thermistors to measure leaf temperatures was developed in Illinois. Initial studies indicate that corn leaves in sunlight were 0.5° C. cooler than the ambient air, while lower green leaves, in the shade, were as much as 6.5° C. warmer than the air. The work appears to indicate that transpiration has a cooling effect on plant leaves and thus may be necessary for plant survival.

In studies of plant-water relations conducted at Ithaca, New York, it was found that the relative turgor of the plant follows a diurnal cycle, the amplitude of which is governed by soil moisture and evaporative conditions. The sequence of conditions involved in drouth status of a plant is: First, there is a loss of turgor; second, loss in turgor somehow hampers the photosynthesis process; and finally, transpiration is decreased.

At Manhattan, Kansas, measurements of net radiation on sorghum plots having two row widths (20 and 40 inches) and two plant populations (60 and 480 sq. in. per plant) showed that for each row width when the plant population was high (60 sq. in. per plant) the crop plants themselves absorbed 93 cal./cm^2/day more energy than when the plant population was low (480 sq. in. per plant). On the other hand, the difference in energy absorbed by the plant under high versus low plant population, was compensated by the amount of energy absorbed by the soil.

At Bushland, Texas, net radiation measurements made over an isolated irrigated grain sorghum field showed that during years of normal weather, the energy equivalent of the evapotranspiration ranged from 109 to 120 percent of the net radiation. As compared to a noncropped field, evaporation from black and white atmometers averaged 7 and 11 percent less, 600 and 50 feet, respectively, inside the upwind edge of the field. Both these observations support the conclusion that considerable energy for evapotranspiration was supplied to the field by advection.

In studies of materials for controlling wind erosion while vegetation was becoming established at Manhattan, Kansas, properly anchored vegetable mulches far exceeded, from the standpoint of cost and effectiveness, new materials that are claimed to be effective in controlling wind and water erosion. At quantities sufficient to control erosion, the total cost was $89 to $150 for hauled-in and anchored wheat straw mulch, $247 per acre for cutback asphalt, $335 per acre for asphalt-in water emulsion, and about $1,000 per acre for latex-in-water emulsion. Wood cellulose fiber was effective in controlling wind erosion at a cost of $95 per acre, but was ineffective in controlling water erosion.

Resin-in-water emulsion was effective in controlling wind erosion of sandy soil at a cost of $213 per acre, but was ineffective in controlling wind or water erosion on fine-textured soil. The vegetative mulch was the only material capable of appreciably reducing runoff. Of the five types of packers tested for anchoring vegetative mulches, the rolling disk packer was by far the most effective.

Contouring provided adequate erosion control for continuous corn grown on long, gentle slopes (420 ft.) of slowly permeable Mexico soil in Missouri during 6 of the past 8 years. However, extremely high soil losses in 1957 and 1961 brought the 8-year average annual loss to 4.3 tons per acre, or about 50 percent greater than the accepted maximum for this soil. The loss in 1961 was nearly 19 tons per acre. These data indicate that local rainfall pattern and soil permeability as well as steepness of slope must be considered when determining maximum field lengths for contoured row crops.

In a contour farming study at Marcellus, New York, begun in 1942, yield benefits of the practice increased significantly during the first two-thirds of the period. Since that time the established level of increase has been maintained on the average, although benefits have fluctuated widely from year to year. Contour benefits for beans during the later period varied the least, ranging from 13 to 30 percent with a mean of 20 percent. With wheat, the range was from 1 to 70 percent with a mean of 25 percent. Corn was the only crop not showing a contour benefit each year. Yield changes ranged from -8 to +36 percent with an average of 10 percent.

Grain sorghum, and dwarf field corn demonstrated optimum yields at water table depths of 24 to 30 inches. Protein and fat contents of grain from sorghum and corn were not affected by depth to water table. Oxygen diffusion in the primary root zone of the crop was quite good where the water table was maintained 18 or more inches beneath the soil surface.

At Weslaco, Texas, in an area where the water table declined from 40 inches at seeding time to 72 inches at plant maturity, soil moisture measurements taken at various growth stages of grain sorghum indicated that a substantial portion of the moisture used by the crop came from the water table.

Corn yields in a corn-Coastal Bermudagrass rotation at Florence, South Carolina, were no higher than those on continuous corn. In the Georgia Piedmont, rotations with legume sod crops increased corn yields by 10 to 20 bushels per acre as compared to the continuously cropped plots, even when 80 pounds of nitrogen was applied.

Rotation experiments in the Southern Plains have shown that two years of alfalfa or sweetclover increased dryland corn yields at Temple, Texas. At Bushland, Texas, the fourth irrigated grain sorghum crop

following two years of alfalfa averaged 500 pounds per acre more than continuous sorghum. At Cherokee, Oklahoma, alfalfa in an alfalfa-wheat rotation supplied sufficient nitrogen for maximum yields of wheat for two years following alfalfa, but nitrogen deficiency developed in third-year wheat.

In western Minnesota, eastern North Dakota, and eastern South Dakota, a combination of management practices that should give the most efficient use of soil moisture are being studied. About one-half of the locations showed a response to variations in corn population, one-third to nitrogen additions, and one-fourth to phosphorus additions. In 1960, good correlations between corn yields and the amount of moisture stored in the soil at planting time were obtained. However, in 1961, rainfall during the growing season was a better indicator of crop yields.

Because stored soil moisture must be relied upon to produce a normal corn crop at Morris, Minnesota, considerable effort has gone into the development of management practices that will increase the amount of water stored from precipitation during the fall and winter. Measurements made in 1961 showed that 22, 43, or 52 percent of the precipitation was stored during the fall and winter if the soil had been fall-plowed, if alfalfa was left standing, or if the soil cover was cornstalks, respectively.

Continued emphasis was placed on landforming and other mechanical means of conserving moisture at Mandan, North Dakota. On a bench terrace experiment, little runoff from the contributing area into the bench terrace took place during the drouth year of 1961. Wheat yields averaged 17.0, 13.3, 7.2, and 3.2 bushels per acre for fallow with no contributing area, continuous wheat with a waterproofed contributing area, continuous wheat with a grass contributing area, and continuous wheat, respectively. Fallow treatments had an unusually good moisture supply at seeding time owing to an optimum previous season. On a field-scale study at Mandan, corn yields averaged 14.1, 8.9, and 2.1 bushels per acre on level benches with contributing areas, level benches without the contributing area, and on the contributing area, respectively.

Land forming in the Red River Valley is more a water spreading practice than a surface drainage practice. Soil moisture is more uniform on land formed plots with consequent better operation of field machinery. Seeding is possible earlier in the spring and tillage is possible sooner after rains. While corn and barley yields on well drained parts of the field may not be increased, land forming increases average yields by both increasing yields on former depressed wet areas in the field and permitting more timely farming of the remaining areas in the field.

Residue management to retain large quantities of prior-crop residues at or near the surface very effectively reduced runoff and erosion from both corn and small grain in tests in five Corn Belt states. During the past 8 years, corn following corn with chopped corn stover mulch and added barnyard manure averaged 80 percent less runoff and 93 percent less soil loss than a corn-oats-meadow rotation without the mulch and manure on Fayette silt loam with 16-percent slope. Comparable results were obtained from a 7-year similar study on Dodge silt loam with 8-percent slope. In an 8-year test on the Midwest claypans, erosion from continuous corn at very high fertility was further reduced about one-third by leaving a mulch of shredded corn stalks on or near the surface. Using a field cultivator instead of a moldboard plow to prepare the seedbed reduced erosion from first-year corn after meadow from 5.9 tons per acre to 1.8 tons at La Crosse, Wisconsin, and reduced soil loss from oats from 12 tons to 5 tons.

At Cherokee, Oklahoma, runoff from small rings placed in field plots was correlated with the plot runoff. The relation was curvilinear and much closer for major runoff-producing storms in which the entire plot area contributed to runoff. Infiltration rates were similar on lovegrass and alfalfa plots. Initial rates were high on wheat plots because of loose surface soil from seedbed preparation. Soil concentration in runoff water was increased 6 times by removing wheat stubble surface residue and 12 times by removing lovegrass top growth with very little influence on infiltration.

On the basis of 1960 and 1961 results at Pendleton, Oregon, vertical mulching is not a recommended practice in the Columbia Basin of Oregon. The mulched trenches reduced runoff and erosion only when they were open to the surface. Tillage and seeding operations after vertical mulching tended to seal the surface with loose soil and essentially eliminated any beneficial effect of the trenching. At harvest time, strips 12 to 20 inches wide over the trenches were bare of wheat. Work near Rockford, Washington, showed that vertical mulching had no appreciable effect on the growth of alfalfa.

Studies on the stratified, high-silt Malheur soils in southeastern Oregon indicate that deep plowing may be useful on these soils. Crop yields were greatly increased the first year after plowing. Water infiltration and water and root penetration were greatly increased. Preliminary data on the change in the salinity and exchangeable sodium content indicate that the salts and exchangeable sodium were markedly reduced within 2 crop years.

Runoff and soil loss data at Watkinsville, Georgia, show there is little hazard from erosion on moderately sloping land, even under very severe rainfall conditions when row crops follow sod crops on contour-farmed land. Rainfall in 1961, totaling over 62 inches was 33 percent above normal and the rainfall erosion index was 200 percent of the

22-year average. Soil loss from a 3-year rotation of fescue, fescue and corn; a 4-year rotation of fescue, fescue, corn and cotton; and continuous cotton was in the ratio 1 to 7 to 47, respectively, and runoff was in the ratio 1 to 3 to 8. These findings strongly indicate that sod-based rotations are essential for production of row crops on sloping Piedmont land if conservation of rainfall and soil are to be attained practically.

Minimum tillage for corn has proved effective in studies in New York and New Jersey and on medium- and coarse-textured soils in Virginia. On clay soils in western Virginia, however, poor stands continue to be a problem. Corn following sod with no tillage, using either herbicides or black plastic to kill the sod, gave yields as high as conventionally tilled plots in Virginia and New York. Soil moisture was higher under the nontilled than under conventionally tilled plots.

In the Corn Belt, minimum tillage for corn has effectively increased infiltration and decreased erosion. From studies using a field plot rainfall simulator in Indiana, soil losses from the third successive year of corn were essentially double those from the first-year corn for both conventional and minimum tillage. However, the relative effectiveness of the minimum-tillage was only very slightly less in the third year of corn than in the first year after sod.

Tests in both Indiana and Wisconsin showed that the potential benefits of minimum-tillage practices may be lost as a result of soil crusting by intense rainfall early in the growing season. When surface crusting was eliminated by cultivation, minimum-tillage reduced soil loss about 40 percent, even when corn was mature. Four or five months after planting, the minimum-tilled plots were still much less compacted than the conventionally treated check plots. During the critical first two months after corn planting, Wisconsin studies showed minimum tillage methods were most effective when plowing and planting were on the contour. Wheeltrack planting on the contour on Fayette silt loam with 16-percent slope lost 0.33 inch in runoff and 0.8 ton soil per acre from natural rainfall, compared with 0.86 inch in runoff and 5.8 tons of soil from adjacent "conventionally" planted corn, also on the contour.

A surface mulch of chopped hay superimposed upon the plow-plant method greatly reduced runoff and almost eliminated soil loss from Russell silt loam, a well-drained soil in Indiana, during two test periods in each of which 5 inches of simulated rain was applied at 2-1/2 inches per hour. About one-half ton of soil was lost from this treatment as compared with 13 tons from a similar minimum-tillage treatment with no mulch. Orchardgrass and alfalfa hay harvested from adjoining strips equal in area to the corn plots were chopped and blown over the corn plots after first cultivation. These preliminary results indicate that this treatment may be very effective in controlling

erosion on short irregular slopes where contour-type conservation practices are not feasible. The plow-plant method would control erosion during the early weeks after planting, the single cultivation would destroy crusts produced by early rainfall, and the mulch would prevent sealing and ready transport of soil by subsequent rainfall without the adverse effects of mulch on soil temperatures in the early spring.

At Sidney, Montanta, chemical fallow has not been as successful as tilled fallow in conserving moisture. This was due largely to incomplete control of wild oats by the chemical. At the Pendleton and Sherman stations in the Columbia Basin of Oregon, chemical fallow (1.6 pounds atrazine plus 1.0 pound amitrole per acre) did not have a significant effect on moisture conservation, nitrate production, or on the population of soil micro-organisms. There was, however, a decrease in grain yield due to the chemical treatment at the Pendleton location (23.1 compared to 29.7 bushels per acre). This depression in yield was not noted at the Sherman location nor at Pendleton on the chemical treatments that were tilled.

Summer fallow tillage experiments for moisture conservation in the dryland winter wheat area of eastern Idaho show that delaying plowing reduces moisture storage at seeding time. When plowing was done early with the soil at field capacity, the available moisture at seeding time was 13.9 percent as compared with 9 percent for the treatment that was tilled when the top 6 inches had lost all available moisture. The treatment tilled when the top 6 inches had lost one-half available moisture had 10.7 percent moisture at planting time.

In comparing annual cropping with summer fallow for spring wheat at St. Anthony, Idaho, it was found that fall chiseling permitted storage of 72 percent of the winter precipitation as compared to 41 percent on the treatments not chiseled. Eighty-six percent of the deviation in yield was accounted for by the amount of stored moisture at the start of the growing season, with each inch of stored moisture producing 2.12 bushels of wheat.

Wheat yields in Nebraska and Colorado and corn and oat yields in Nebraska have been less on stubble-mulched plots than on conventionally tilled treatments. Laboratory studies at Lincoln, Nebraska, show micro-organisms may produce phytotoxic substances which, in some cases, could account for yield reductions of wheat and corn.

Experimental results obtained at Ames, Iowa, demonstrate that crop residue mulches may decrease the availability of manganese needed for early growth of corn. Mulched corn plants sampled 25, 34, and 41 days after planting contained 81, 32 and 34 ppm of manganese, respectively, as compared to clean-cultivated plants with 145, 69, and 40 ppm.

In Mississippi, corn yields did not differ significantly when planted in mulch, tractor tracks, or a well-prepared seedbed. Six tons of corn residue left on the surface over winter and partially incorporated at planting time reduced growth, nitrogen uptake and yield of succeeding corn crop by about 25 percent. Plowing under the residues partially eliminated these reductions. The carryover of fall-applied nitrogen was the same for all residue management systems.

At Bushland, Texas, wheat on fallow appeared to be able to extract moisture from the fifth and sixth feet of soil more effectively than did continuous wheat. This may have been due to more extensive rooting systems in the fallowed wheat.

Corn yields on Moody silt loam in Iowa have been higher on conservation tillage practices than on conventional practices under conditions of low soil moisture at planting and/or midsummer drouth. Under favorable moisture conditions, yields were not greatly different among the tillage methods tested.

At Cherokee and Woodward, Oklahoma, clean-tilled land outyielded stubble-mulched land when no fertilizer was applied, but wheat yields on stubble-mulched land were equivalent or greater than on clean tilled when 40 pounds of N was applied.

At Riverside, California, in a dryland alternate fallow-grain system, both a knowledge of available soil moisture and nitrogen (or potentially available) at planting time are required in predicting what the effect of applied nitrogen will be. On a rangeland study in a season with one-third average annual rainfall, the soil moisture was more efficiently used when 60 pounds of nitrogen and 14 pounds of phosphorus per acre were applied.

Studies conducted at Fort Collins, Colorado, show that the effect of soil texture on available P and the amount of fertilizer P needed to produce equal rates of P uptake could be explained more adequately by applying the concept of diffusion of P. Differences in rates of uptake predicted from diffusion equations were observed in actual measurements of rates of P uptake by plants. As a result of this approach, a sound basis is provided to develop a method for determining the amounts of fertilizer phosphorus needed to give equal levels of available phosphorus on soils varying in texture. A clay soil requires two to three times as much fertilizer phosphorus as a fine sandy loam (calcareous or alkaline soils) to produce the same plant response when both soils are initially very low in available phosphorus. An exact quantitative evaluation of this textural effect has not been possible because of variations in maximum yields among soils.

Short-term phosphorus uptake studies were conducted at Fort Collins, Colorado, with intact month-old corn plants of differential nitrogen and phosphorus composition. Supplemental nitrogen pretreatments producing increased growth rates and higher levels of nitrogen in the plant, stimulated the rate of phosphorus uptake per gram dry weight of root more than tenfold. The presence of nitrate or ammonium ions in the test solution during the uptake period had negligible effects on phosphorus uptake rates. The increases in phosphorus uptake rates may be general effects of the increasing demand for phosphorus within the plant with increased growth rates, but the magnitude of these effects suggests a more direct connection. Phosphorus uptake rates were highly correlated with total nitrogen level in the root.

Results of study on the influences that stage of barley growth and soil moisture tension have on the absorption of P conducted at Bozeman, Montana, showed that most of the P was absorbed by barley in the tillering to heading stage. No P was absorbed from a soil near the wilting point. However, uptake started eight hours after the soil was brought to field capacity on a fine sandy loam soil and after 32 hours on a silty clay loam. A high moisture zone did not aid the plant in removing P from an adjacent low moisture zone.

Studies to determine the best combination of corn population, fertilizer, and other management practices for efficient moisture use in western Minnesota, eastern South Dakota, and eastern North Dakota showed that corn population, nitrogen additions and phosphorus additions increased the water use efficiency values.

At Akron, Colorado, moisture studies with grain sorghum have shown that approximately 9 inches of water (growing season rainfall plus moisture stored in the soil at planting time) are necessary for a bushel of grain to be produced. Average growing season rainfall (June-August) is 7.2 inches. Soil moisture utilization in the profile was increased 1 inch by the addition of 60 pounds of N. Maximum moisture use occurred during the time the plant was making rapid elongation.

Results of greenhouse experiments conducted at Beltsville to study soil N uptake at various fertilizer N levels have shown that the uptake of soil nitrogen by oats increased with increasing rates of fertilizer nitrogen. The maximum effect of N application on the uptake of soil N for the 12 soils studied averaged about 30 percent above the control. The percentage uptake of fertilizer nitrogen also increased with rate of application. Present evidence indicates that such differences in nitrogen uptake can be best explained by the differential immobilization of mineral nitrogen by rhizosphere micro-organisms in the utilization of energy material derived from roots of varying carbon-nitrogen ratios.

In an experiment to study the effects of nonuniform fertilizer distribution on corn yields in South Carolina, results showed that fertilizer distribution could vary as much as 40 percent from uniformity without causing a significant yield decrease. In this study all whole plots received the same amount of fertilizer but the distribution pattern in rows varied.

Studies on the availability of residual nitrogen from applied ammonium nitrate fertilizer to summer fallow wheat were continued at Pendleton, Oregon. Where more than 80 lb/A. N were applied for the 1959 crop, sufficient residual N was available to increase yields of the next (1961) wheat crop. It now appears that successive applications of about 40 to 50 lb/A. N on each wheat crop is adequate to maintain maximum yields in the 15- to 16-inch rainfall area. In the 11- to 12-inch rainfall area, about 30 lb/A. N appears to be adequate.

In another experiment, urea and ammonium nitrate, respectively, were used as the sole nitrogen carrier in 1:1:1 liquid fertilizers applied in different amounts up to 150 pounds per acre, and according to different time schedules, to corn growing on Davidson silty loam soil in greenhouse culture. The stover yield and phosphorus uptake increased with the amount of fertilizer applied in all treatments and were significantly greater with ammonium nitrate than with urea.

Current trends for the higher use rates of fertilizer in crop production have imposed new parameters on the concept of nutrient balance and absorption in relation to yield. At Beltsville, Maryland, the interrelations between cation and anion uptake and content of plants have been reexamined. Under conditions where high amounts of fertilizers are used, research results show that the main function of cations is to supply positive charges which enables the plant to maintain the pH and the organic acid content within a narrow range, and that this is a prerequisite for good growth. This information will allow a more rationalized method for composing fertilizer mixtures to be developed.

A direct physical picture of the pathway of ion uptake in the plant roots is needed to clarify the role of the soil as a source of nutrients in relation to the ion uptake process by the plant root. Techniques have been developed for preparing high resolution autoradiographs. This is the first step in determining the initial sites of ion entry and accumulation.

Hexadecanol, a straight-chain alcohol, is known to form a film on a water surface, such as a pond, and to reduce evaporation. It has been suggested that hexadecanol might form a similar film on the evaporating water surfaces within a plant or soil, and thus decrease evapotranspiration. Corn was grown in the greenhouse in Illinois in containers which were sealed to prevent evaporation from the soil.

In two experiments hexadecanol caused the plants to use less water, but only by causing the plants to grow less. The amount of water used per square centimeter of leaf was unchanged. In other greenhouse experiments hexadecanol additions did not reduce evaporation losses from clay or loam soils but did cause a significant decrease loss from sand. Much of the water movement above the water table in coarse sand is by vapor transfer, whereas most of the water movement in finer materials is by capillarity. Hexadecanol might be expected to interfere with vaporization within the soil more than with capillary movement.

Two comprehensive field experiments were conducted in Illinois in 1961 in which water use by corn was measured as influenced by broadcasting and banding additions of octa-hexadecanol to the soil. In one experiment the soil surface was completely plastic-covered and hence transpiration and drainage were the mechanisms of water loss. In the other experiment the soil was not covered and thus evaporation was an added component of water loss. No statistically significant difference in either water use or corn yield occurred as a result of octa-hexadecanol application. There was, however, a slight, but statistically significant, reduction in plant height associated with the octa-hexadecanol treatments. It was also found, in a laboratory experiment, that a synthetic resin did appreciably reduce soil evaporation; however, the application made the soil surface resistant to wetting.

The effect of octadecanol on the evapotranspiration rate of corn was studied in the greenhouse at Tempe, Arizona. Three rates (670, 3,350, and 16,750 pounds per acre) and two placement methods (thoroughly mixed and banded 8 cm below the surface) were used. During the first 18 days after seeding there was no significant effect upon evapotranspiration by the above chemicals. During the eight weeks of growth, two cycles of evapotranspiration showed no effect of octadecanol on lowering water loss as compared to control values. An early tendency to stunting at the 25-g dosage rate did not result in any significant difference in final dry weight between treated and control plants.

Corn grown on plots covered with white plastic at Fort Collins, Colorado, yielded 16 percent more than corn grown on plots with no cover and 5 percent more than corn grown on plots with a black cover. Water was not a limiting factor in this experiment. Sensible heat from the soil surface to the air, calculated from air temperature gradients, was increased 130 percent by covering the soil with black waterproofing and decreased 44 percent by covering the soil with white waterproofing. These data indicate that energy not used to evaporate water in the soil can be reflected if the water-proofing material is light in color. In an evaporation study using lysimeters at La Crosse, Wisconsin, water use by corn on covered plots was 49 percent of that for the corn grown on the uncovered lysimeter.

A transparent plastic mulch used at Marcellus, New York, increased soil temperatures and early plant growth. Corn yields on the control plot were 109 bushels as compared to plastic mulch yields of 124 bushels for the normal season hybrid and 134 bushels for the late hybrid. On plots with a sealed plastic cover, 113 bushels of corn per acre were produced with the estimated 6-8 inches of available water at planting time. At no time during the season was there evidence of moisture stress.

Feed and Forage

Muscular dystrophy in livestock is distributed in a geographic pattern which suggests that soil and plant composition factors may be associated with the prevalence of this nutritional disease. Inasmuch as the addition of very small amounts of selenium to the ration has protected livestock from muscular dystrophy, attention has been focused upon the selenium content of livestock feeds in relation to this problem. Existing evidence does not clearly establish a relationship between the selenium content of the forages from various areas and the incidence of muscular dystrophy in livestock in the area. During the past year, samples of forages have been obtained from a number of farms and ranches where muscular dystrophy was known to be prevalent, and from similar properties where muscular dystrophy is not a problem. These farms and ranches are located in several different parts of the United States. These samples were collected in cooperation with the Animal Husbandry and Veterinary Science Departments of Oregon State University, University of Nevada, Cornell University and the Texas Agricultural Experiment Station. Currently, efforts are being directed toward development of methods for measuring the very small amounts of selenium present in these forage samples, and to comparisons of the selenium content of feeds from farms where muscular dystrophy has been prevalent with those where it has not occurred. The relationships between the content of selenium and other substances which might interfere with selenium metabolism will also be determined.

Along with this survey of the selenium content of forages, contract arrangements have been developed with Oregon State University to study the effect of addition of selenium to the soil upon the incidence of muscular dystrophy in sheep. In this study, selenium will be added to a part of a hayfield on a ranch which has had in the past an incidence of muscular dystrophy. Hay from the treated portion of the field will be fed to ewes in comparison with hay from the untreated portion, and the incidence of muscular dystrophy in lambs born to these ewes will be determined.

The molybdenum content of vegetation growing on poorly drained wet soils is often higher than that found in similar plants growing on the better drained and drier soils formed from the same parent material. A study of the effect of soil moisture level per se upon the uptake of

micronutrients by plants might serve to explain variations in micronutrient contents of plants growing on different kinds of soils and in different seasons. For this reason, a greenhouse study has been conducted to measure the influence of soil moisture level upon the uptake of trace elements by alsike clover. Four soils with a known history of cobalt deficiency or molybdenum toxicity are included in the experiment. Alsike clover is grown at a high moisture level (water table at 7" depth) and a low moisture level (0.3 to 10 atmospheres suction) on each soil.

In the first two cuttings from this experiment, the molybdenum content of the plants was about twice as great on the wet treatments as on the dry treatments on all soils. These findings indicate that a high moisture level per se is a factor in the high molybdenum content found in vegetation growing on wet soils, and that improved drainage of these soils may help to reduce the molybdenum content of the forage.

In cooperation with the University of Georgia, Animal Husbandry Department, and the Southern Piedmont Conservation Experiment Station, a study of the effect of nitrogen fertilization upon the nutritional quality of Coastal Bermuda hay was conducted. Two lots of hay, one produced with an annual application of 100 lbs. N per acre, and one produced with an annual application of 675 lbs. N per acre, were fed to grade Angus steer calves for 140 days in a ration of hay, salt and cottonseed meal. The steers fed the hay produced with the high level of nitrogen gained 1.11 lbs. per day during this period, and consumed 12.5 lbs. of feed per pound of gain. The steers fed the hay produced at the low level of nitrogen fertilization gained .96 pound per day and consumed 14.1 lbs. of feed per pound of gain. Thus, under the conditions of this experiment, the hay produced at the high level of nitrogen fertilization was slightly superior to the hay produced at the low level of N fertilization.

In studies of the fate of 640 pounds of nitrogen applied to crested wheatgrass at Newell, South Dakota, nitrate-nitrogen analyses accounted for one-third of the fertilizer nitrogen on irrigated plots and over two-thirds of the fertilizer-nitrogen on the dryland plots after one winter and one cropping period. Considerable fertilizer nitrogen could not be accounted for in the soil nitrogen fractions studied. Wide differences in unaccounted for fertilizer nitrogen existed between irrigated and dryland plots. Variance ratios for the irrigated plots for soil depths from 0 to 18 inches indicate no significant fertilizer treatment effects on the ammonia-N, hydrolyzable ammonia-N, amino acid-N, or the residue-N fractions. Considerations of the amounts of unaccounted for fertilizer nitrogen in comparison to native soil nitrogen illustrate the difficulties involved in trying to determine balance sheet figures.

Nitrogen recovery by Bahia and Coastal Bermudagrass was studied over a 6-year period at Thorsby, Alabama, both under nonirrigated and irrigated conditions. The percent recovered by Coastal under irrigation varied from 87 percent at the 300-pound annual N rate to 76 percent at the 900-pound rate. On the nonirrigated treatments, the percentage recovered was about 10 percent less than for the irrigated treatments. Coastal recovered a higher percent of the applied N than Bahia.

The Beltsville Laboratory has cooperated at Thorsby, Alabama, on a field experiment in which N^{15} nitrogen fertilizer was used on Sudan grass to study movement and recovery of fertilizer nitrogen. From 10-15 percent of the added N^{15} could not be recovered from the plants or soil, so it was assumed to have been lost in the gaseous form. Recovery from cropped soil was somewhat greater than from uncropped soil. Nitrogen recovered was not influenced by time of application or the ammonium sulfate or sodium nitrate sources. Recovery from uncovered plots was as high as from plots protected with plastic covers.

In a N uptake study at different moisture levels at Mandan, North Dakota, water use efficiency was increased severalfold in bromegrass by the use of nitrogen. Rooting depth and moisture extraction was deeper on the N-treated plots, and seasonal water use was an inch greater than the check treatment.

Runoff and soil loss data at Watkinsville, Georgia, show there is little hazard from erosion on moderately sloping land, even under very severe rainfall conditions when row crops follow sod crops on contour-farmed land. Rainfall in 1961, totaling over 62 inches was 33 percent above normal and the rainfall erosion index was 200 percent of the 22-year average. Soil loss from a 3-year rotation of fescue, fescue and corn; a 4-year rotation of fescue, fescue, corn and cotton; and continuous cotton was in the ratio 1 to 7 to 47, respectively, and runoff was in the ratio 1 to 3 to 8. These findings strongly indicate that sod-based rotations are essential for production of row crops on sloping Piedmont land if conservation of rainfall and soil are to be attained practically.

Preliminary results from Chickasha, Oklahoma, indicate that several grasses have sufficient flood-water inundation tolerance to withstand the normal expected duration and depth of flooding that occur during early spring. The ability of an individual grass to withstand flooding was affected by the interactions of depth, stage of growth, and duration of flooding. Grasses showing most promise are bermudagrass, some switchgrass selections, buffalograss, vine-mesquite, and prairie cordgrass. Grasses showing poor flooding tolerance include King Ranch bluestem, big bluestem, El Kan bluestem, weeping lovegrass, alkali sacation, and eastern gamagrass.

At Tempe, Arizona, controlled experiments on uptake of water were conducted in the laboratory. Relative root activity measurements were made on sorghum plants that were subjected to higher moisture stresses than those ordinarily encountered in an irrigated field of this area. The technique involved the determination of radioactive phosphorus-32 in the plant leaf after the radiotracer had been injected into the soil at varying distances from the plant. The data show that the rate of root growth is about 1 to 1.5 inches per day and the root extension is 30 inches laterally and at least 60 inches vertically from the plant row. Relative root activity distribution patterns were similar for all the irrigation levels investigated. Approximately 90 percent of the root activity is in the 10-inch lateral and 36-inch vertical distances from the plant. The relative root activity distribution is related closely to the moisture depletion patterns in the surface three feet as measured with the neutron moisture probe. It is thus evident that nutrient and water absorption for this crop occur concurrently and to a large extent above the 3-foot depth.

At Bushland, Texas, three years' results indicate that deep plowing and vertical mulching Pullman clay loam did increase the water intake rates but did not affect yields. Measurements made over the 3-year period show the effectiveness of the treatment did not decline with time. Forage sorghum residue used for the vertical mulch could still be identified after three years.

At Akron, Colorado, conservation-bench terraces stored 1.6 to 3.0 inches of available water, which was 23 to 43 percent of the precipitation. Leveled and diked areas, formed to use runoff from other areas, stored from 2.3 to 4.6 inches of water. Snow trapping studies at Akron showed that double sorghum rows properly spaced accumulated from 1.2 to 1.5 inches of water from the 3.77 inches of precipitation that fell as snow. Corn proved relatively unadapted as a barrier material for the conditions at Akron.

Water intake rates were measured in North Dakota rangelands on sites that had been heavily, moderately, and not grazed. During one-hour tests, average intake rates were 1.48, 2.15, and 4.27 inches per hour for the heavy, moderate, and non-grased plots. Eighty-eight percent of the variation in intake rates was associated with amount of standing herbage and the mulch material on the plots. In Arizona, plots with good cover (6,570 pounds per acre) had intake rates three times those of plots with sparse cover (317 pounds per acre) during the first 30 minutes of testing. During the second 30-minute period the plot with good cover took in nine times more water than the plot with poor cover.

Water use efficiency of several varieties of forage sorghums and Sudangrass were evaluated at Akron, Colorado, under heavier than normal rainfall. Water use efficiencies varied considerably among varieties within a species. This work points out the possibility of selecting varieties on the basis of water use efficiency.

The effect of low root temperature and atmospheric saturation deficit on the transpiration of four alfalfa varieties was investigated in four controlled environmental experiments at Tempe, Arizona. These experiments emphasize the fact that wilting, which occurs when absorption is less than transpiration, depends on root temperature, concurrent transpiration rate, and the duration of the imbalance between the two processes. The transpiration rate occurring when the root temperature was at 5°C for four hours was depressed 70 percent as compared to the control (28°C). Transpiration rates at root temperature of 10°C were 20 percent less than the control.

In the first year of studies at Pullman, Washington, on the cause and control of the "alfalfa sickness" problem a marked growth response and effective nodulation was obtained when P, S, and lime were applied and when the soil profile was mixed to a 4-foot depth. No response occurred on the soil aeration or vertical mulching treatments.

A greenhouse experiment made at the instance of Crops Research Division, was concerned with high-level fertilization of bluegrass with superphosphate on Evesboro loamy sand soil. Significant increases in response to phosphorus were observed up to 2,000 pounds of phosphoric oxide per acre.

On a range study near Riverside, California, the application of N and P gave 54 and 98 additional pounds of dry range forage per inch of moisture used on a rocky slope and a swale site, respectively. Either element applied alone did not increase yield.

At Bushland, Texas, water use with blue grama was the same on plots receiving N, which yielded 7,000 pounds forage per acre, as on the plots not treated, which yielded 1,310 pounds. Water use efficiency was increased more than fivefold by applied nitrogen.

In Georgia, moderate rates of potassium applied after each cutting to Coastal Bermudagrass maintained a more nearly optimum level of production and nutrient content in the plant than a single annual application. In Puerto Rico, yield and protein content of Guinea grass were more uniform throughout the year when the nitrogen and potassium fertilizer were applied in 4 or 8 equal applications rather than split into two applications.

Studies on time of application of nitrogenous fertilizers to mountain meadows in western Wyoming showed that fall application was not as effective as spring or spring-summer application at two locations out of four. Nitrogen source made no difference in increasing yields, and 80 pounds of N per acre more than doubled yields regardless of when it was applied.

Oilseeds and Peanut

At the U. S. Soil, Plant and Nutrition Laboratory at Ithaca, New York, during the past year, three additional γ-glutamyl dipeptides have been isolated in crystalline form and their identity conclusively proven by comparison with synthetic dipeptides. Soybean seeds were the source of the two other isolated dipeptides. These compounds have been shown to be γ-L-glutamyl-L-tyrosine and γ-L-glutamyl-L-phenylalanine. The identity was conclusively proven by comparison with synthesized dipeptides. The tyrosine dipeptide has not previously been reported to exist in plants although the phenylalanine peptide has been isolated from onion bulbs.

It is noteworthy that there was about 500 times as much -alanine in the dipeptide form than unbound in the iris tissue. An analogous situation is found in soybeans where there was twenty-seven times as much tyrosine and seven times as much phenylalanine in the dipeptide form as in the free form.

Two greenhouse water-culture studies in which soybean seedlings were sprayed with a solution of 200 p.p.m. of the growth retardant Amo 1618 have been completed. The osmotic pressure of the tissue fluids was of primary interest as a putative factor in the increased salt tolerance of treated plants. The osmotic pressure of leaf saps was consistently lower in Amo-treated plants, averaging 0.3 atm. less than the control leaves in five determinations made at intervals during the week following the spray treatment. The osmotic pressure of stem- and root-saps, on the contrary, tended to be higher for the plus-Amo than the control plants by a like amount. Although a definite effect of this retardant on osmotic pressure of tissues is indicated, the effect appears too small to account for the large difference in response to abrupt salination reported by Marth and Frank. Stem elongation during the week following Amo-treatment was affected by the retardant amounting to a 42 percent reduction in the treated plants compared to the control.

In a second experiment, Amo-treated and untreated cultures were subjected to three salinity levels (0, 1.5, and 3.0 atm. added sodium chloride) from May 29 through July 3. The growth retardant caused a 43 to 51 percent reduction in top growth at the three salinity levels, with a marked increase in leaf-stem ratio over the controls, indicating again the pronounced effect on stem elongation which for the amo-treated plants was only 26 to 32 percent of the controls at the three salinity

levels. Salinity caused approximately the same percent reduction in top growth for the Amo-treated plants as for the nontreated ones. In this test, the growth-retardant effects of Amo 1618 and salinity were, therefore, additive, and salinity exerted as great a growth-depressive effect on the Amo-treated plants as on the controls. The osmotic pressure of leaf sap was again slightly depressed by the Amo-treatment in the absence of salinity but was higher under saline conditions. Stem osmotic pressures were consistently higher for the plus-Amo cultures, while root osmotic pressures showed no significant effect of Amo-treatment. The usual effects of salinity on osmotic pressure of all organs were also apparent. The results to date indicate that osmotic-pressure changes in the plant may favor an increased resistance to abrupt changes in the osmotic pressure of the medium but that tolerance to a continuing state of salinity is not increased thereby. In fact, growth (and presumably yield) reflects the depressive influence of both salinity and retardant. Further studies are contemplated with a variety of retardants and treatment levels.

Iron is more often deficient in plants than any other minor nutrient element. At the Pioneer Laboratory on Mineral Nutrition, Beltsville, Maryland, the compounds keeping iron in a soluble form in plants have been identified. Soybeans were used in some of these studies. Exudates were collected from normal and iron deficient plants. The combination of iron was established by electrophoresis and found to be chiefly with two plant acids, malic and malonic. The varying capacities of roots to reduce iron before it has been absorbed has been demonstrated. After the iron enters the plant it is again oxidized.

Preliminary results obtained by field studies in 1961 indicated that most of the nodules formed on soybean plants grown in areas with a large population of soybean organisms are formed from those already in the soil and not from the inoculum. This emphasizes the need for selecting highly competitive and high nitrogen-fixing strains for use as inocula. This problem has been attacked by classifying the rhizobia into serological groups and by taking advantage of the fact that many strains of soybean nodule bacteria produce chlorosis.

At Auburn, Alabama, in an experiment to determine the factors involved in root development in subsoils with low pH values and high levels of exchangeable aluminum, it was found that soybean roots were quite tolerant, cotton roots moderately tolerant, and sudangrass roots very sensitive to these subsoil conditions. Marked improvement in sudangrass root development in acid subsoils resulted from liming. In all cases the surface soil environment was favorable.

The results of studies to provide insight into the mechanism by which growth retardants increase the tolerance of soybeans to high fertilizer applications indicates that osmotic-pressure changes in the plant may favor an increased resistance to abrupt changes in the osmotic

pressure of the medium but that tolerance to a continuing state of salinity is not increased thereby. In fact, growth reflects the depressive influence of both salinity and retardant. Study of the dynamic aspects of osmotic-pressure adjustment in plants confirms the importance of potassium in effecting short-term osmotic adjustments. Salinity stimulates the potassium increase during the day, but even during the first day of adjustment, other ions may begin to displace potassium in effecting a steady-state adjustment to salinity.

Studies in North Carolina with controlled water tables and plant environment showed that growth of soybeans was inversely proportional to depths to water tables that ranged from 6 to 36 inches when the controlled ambient temperature was 72° F. At 80° F., growth was directly proportional to depth to water table, and at 90° F., growth was not affected by depth to water table. Leaf temperature of soybeans was not affected by water table depth.

In South Carolina, soybeans planted directly in grain stubble and corn planted directly in Coastal Bermudagrass gave yields equal to those on conventionally prepared seedbeds.

Safflower production in nonirrigated regions of the Great Plains area depends primarily on the supply of available soil moisture. Weed-free safflower plots at the Sidney, Montana station have produced about twice as much seed as nonweeded plots. It is recommended that the chemicals, Proban and Monsanto 17029 be tested again on a small plot basis in 1962. The rate of application should be increased for Proban, since it has shown no injurious effect of safflower. Monsanto 17029 should be tested again at about the same rates of application, and both chemicals should be applied when the weeds and safflower crops are very small.

Cotton and Cottonseed

The rapid rise in the use of supplemental irrigation in recent years has increased the need for a criterion for determining when water should be applied to plants. At Weslaco, Texas, the use of moisture stress within the plant as an irrigation criteria for cotton indicates that the method can very readily be used for determining when to irrigate. Excellent control of timing of irrigation applications was obtained, based on relative turgidity measurements made on cotton leaves. The time of wilting of the cotton plant was strongly indluenced by the amount of moisture in the first foot of soil. However, for any given soil moisture condition, the time of wilting was also associated with the temperature and vapor pressure around the plant. Although this method offers considerable possibilities in determining when to irrigate, additional studies will be required before the principal can be applied to farmers' fields.

At Thorsby, Alabama, black plastic mulch over the drill row and clear plastic fences four-feet high at intervals in the field raised soil temperatures, increased the early growth of cotton, hastened maturity, and increased total yields. Topping well-fertilized, irrigated cotton plants at either 36, 42, or 48 inches high and pruning side branches hastened maturity, increased yields, and improved the quality of lint. Benefits obtained from this treatment were associated with microclimatic changes in the cotton.

Research results confirm that excessive strength of the tillage pans in the Southern Great Plains is the cause of reduced plant growth and yield. The soil strength is created by an increase in soil bulk density, a decrease in soil moisture content, or a combination of the two factors. At Woodward, Oklahoma, moldboard plowing deep enough to disrupt the tillage pans did not increase sorghum yields. Disking a compact Amarillo fine sandy loam to a depth of 8 inches decreased the strength to a desirable level, but chiseling to a depth of 10 inches only created a trench filled with low strength soil. Cotton roots developed normally in zones of low strength, but could not develop in zones of high strength.

In studies at Weslaco, Texas, evapotranspiration rates of cotton were influenced by the amount of available moisture in the profile. Evapotranspiration rates were highest during the blooming and fruiting stages of growth but leveled off during the boll development period. If the cotton plant had sufficient moisture during the early bloom stage, yields were the same on plots irrigated at 50 and 25 percent available moisture.

At Big Spring, Texas, cotton planted in skipped row systems, such as two rows planted and one row skipped, or two rows planted and two rows skipped, gave higher row-acre yields but made no difference on a comparable acre basis than did the standard row spacing. Results from a 4-year study showed that dryland cotton on Amarillo fine sandy loam seldom used all of the available moisture in the fallow portion of a four-cotton row, four-fallow row system. Cotton used all or nearly all of the soil moisture in a two-cotton row, two-fallow row system. All moisture was extracted in a two-cotton row, one-fallow row system, or a one-cotton to one-fallow row system.

In other studies at Big Spring, Texas, soil moisture data obtained with cotton and grass in rows indicate that cotton utilizes moisture as effectively as native perennial grass, but with cotton the rapid moisture use is delayed until the heavy fruiting period. Some of the shorter native grasses use little moisture to a distance greater than 60 inches but taller grasses such as Blue Panic may utilize moisture to a distance of 80 or more inches from the planted row.

Runoff and soil loss data at Watkinsville, Georgia, show there is little hazard from erosion on moderately sloping land, even under very severe rainfall conditions when row crops follow sod crops on contour-farmed land. Rainfall in 1961, totaling over 62 inches was 33 percent above normal and the rainfall erosion index was 200 percent of the 22-year average. Soil loss from a 3-year rotation of fescue, fescue and corn; a 4-year rotation of fescue, fescue, corn and cotton; and continuous cotton was in the ratio 1 to 7 to 47, respectively, and runoff was in the ratio 1 to 3 to 8. These findings strongly indicate that sod-based rotations are essential for production of row crops on sloping Piedmont land if conservation of rainfall and soil are to be attained practically.

Land forming in the cotton lands of Louisiana have greatly improved water management and enabled more efficient use of crop production equipment. Row grade and length studies are under way for these soils.

At Weslaco, Texas, cotton burs applied as a heavy residue cover to a highly saline soil surface facilitated the removal of salts from the surface 42 inches in a period of 8 months. Much of the removal occurred in the first 5 months. Resulting salt concentrations were below levels known to adversely affect plant growth. Salt removal was also facilitated, but to a lesser degree, by establishing a permanent ridge-furrow surface management system.

At Big Spring, Texas, deep placement of fertilizer on cotton showed no advantage over placement at conventional depths.

Although not essential for growth, sodium is absorbed and translocated by plants, the amounts involved varying widely among plant species. Sodium is absorbed by the roots of bean plants but is not translocated appreciably to the stems, petioles and blades. In cotton, however, it is absorbed by the roots and readily translocated to the stems, petioles and blades. A study has been initiated to determine the factors which regulate the absorption and translocation of radioactive sodium in these plants. Dinitrophenol, a metabolic inhibitor, caused a decrease in the total amount of sodium absorbed by the plant at 25°C., particularly in the case of cotton. A decrease in temperature from 25° to 5°C. caused an even greater reduction in the amount of sodium absorbed by either plant, but dinitrophenol had no additional effect at the lower temperature. In addition to reducing the total amount of sodium absorbed by the plant at 25°C., dinitrophenol caused an increase in the amount of sodium translocated to the stems, petioles and blades of beans. In the case of cotton, there was a decrease in the amount of sodium retained by the roots. At 5°C., these changes in translocation attributable to dinitrophenol are less evident or even nonexistent. Many of the changes in absorption and translocation could be due to changes in the permeability of cell membranes. Dinitrophenol affects the permeability of membranes as well as the

metabolic activity of plant cells. It is hoped that experiments designed to determine the exact location of sodium in the cells of cotton and bean plants will provide information concerning the mechanism of translocation in these two species.

Potato

A serious growth abnormality with the appearance of "fern leaf" symptoms in Russet Burbank potatoes in the Columbia Basin Irrigation Project has been diagnosed as a zinc deficiency by research conducted at Prosser, Washington. This deficiency, occurring on areas of newly leveled land, was aggravated by applications of phosphate fertilizer. The deficiency was corrected by supplementing the necessary N plus P fertilization with 10 pounds Zn per acre applied as $ZnSO_4$.

Decomposition of plant residues is known to have a pronounced effect on the survival of plant pathogenic micro-organisms in soil, but not enough is known about this effect to make use of it in management practices for root disease control. In continuing attempts at Prosser, Washington, to understand these processes, it has been found that decomposition of plant residues in soil in the absence of oxygen is quickly lethal to the fungus causing the verticillium wilt disease of potatoes. Prolonged anaerobic fermentation leads to drastic reduction in the populations of soil fungi in general, suggesting that other root pathogens may be similarly destroyed. The effect appears to be due to the production of fermentation products that are fungitoxic. The controlled production of anaerobic conditions in soil may be a feasible control practice against these disease-producing soil organisms.

Other laboratory studies at Prosser, Washington, have produced mutant strains of the soil-inhabiting potato-scab organism that have high resistance to the antibiotic streptomycin yet retain their pathogenic abilities. This finding furnishes evidence that this process may occur in soil, indicating that soil treatment with fungicides may lead to the appearance of new resistant strains.

In northern Maine, heating cables and plastic mulches were used early in the season to increase the temperature under potatoes. In June and early July, soil temperatures on the plots with the heating cable were 10 to 15 degrees higher than on the control. Temperature under the plastic tended to be slightly lower than the heating cable treatments. Plants on the plots with higher temperature emerged two weeks earlier and flowered one week earlier than on the control. At harvest time tuber yields were the same for all treatments.

The length of the growing season affected potato quality but had little effect on yields. Early planted potatoes had a significantly higher specific gravity and ascorbic acid content than the late planted potatoes.

An experiment was designed to measure erosion and runoff losses from potato fields. The treatments are natural soil, rocks removed, rocks crushed, fallow, and a rotation of potatoes, oats and sod.

Nine of seventy-eight storms contributed to more than 75 percent of the soil loss. The soil factor "K" for the universal soil loss equation was calculated to be 0.37 tons/acre. For these nine storms, an average of 57.5 percent of the rainfall was lost as runoff. During five of these storms better than 70 percent of the rainfall was collected as runoff. This was due to the high moisture content throughout the season.

Soil losses from plots where rocks were removed were significantly higher than from the natural or crushed rock treatments. This followed the same trend observed in 1960. Higher water losses were also measured where the rocks were removed. Soil loss from the rotation plots was 32 percent of the soil lost from the continuous potato treatment.

In north central North Dakota the effect of nitrogen and phosphorus fertilization on crop yields under irrigation was evaluated in a nonlegume rotation (barley, corn, potatoes) and in a legume rotation (barley, alfalfa, alfalfa, alfalfa, corn, potatoes) on Gardena loam. In the nonlegume rotation, yields of all crops were increased by nitrogen. Phosphorus alone decreased yields of corn forage. However, with adequate nitrogen, phosphorus increased yields of barley, corn, and potatoes. In the legume rotation, the major effect of alfalfa was to supply available nitrogen.

Vegetable

In the controlled-climate growth room at Watkinsville, Georgia, radiant energy, vapor pressure deficits, plant size, and age of plant accounted for 86 percent of the variation in transpiration of kidney beans. This defines for this crop the parameters in which modifications are possible. The stomata and their guard cells were studied, particularly in relation to transpiration. Stomatal opening of sorghum plants increased as light intensity and humidity increased, but there was no direct relation between stomatal opening and transpiration. Increased soil moisture tension above 0.15 atmosphere reduced transpiration, and tensions above 4 to 5 atmospheres reduced stomatal openings in sorghum plants.

At the U. S. Salinity Laboratory, Riverside, California, it was found that the migration of ions from soils to plants is characterized by three distinct stages. First, the ions dissociate from the adsorptive surfaces of the soil and enter the soil solution. This process, triggered by the general movement of ions in the direction of plant roots, is to restore or maintain ionic equilibrium between soil

surfaces and their aqueous surroundings. The second stage consists of a translocation of the now more or less soluble ions towards the root surface. In association with the movement of water, this translocation is predominantly characterized either by mass flow, or by diffusion. Diffusion will prevail if the aqueous phase becomes increasingly constrained by electric field forces extending from root and soil surfaces. This is generally the case under arid conditions. The third stage consists of an exchange process involving root-produced hydrogen ions, followed by a translocation of the entering ions to inner areas of the cells. This process may be speeded up by water uptake, but is never determined by it. Results of studies with red kidney beans indicate the occurrence of a preferential uptake or exclusion of ions relative to water characterizing the nutrition of plants. This suggests that crop management recommendations should be based on information which includes the diffusivity of the soil for water and ions under prevailing moisture conditions.

At Norfolk, Virginia, supplemental irrigation with dilute sea water reduced yields of tomatoes, beans, potatoes, and onions only at high salt levels and the degree of reduction generally conformed to accepted salt tolerance values for these crops. There was enough residual salinity from these spring crops to affect the fall plantings of beans and peas. Alfalfa, fescue, and orchardgrass were more salt tolerant than the vegetable crops studied. Greenhouse studies indicate that the length of time the plant roots are exposed to a saline substrate may be a more critical factor than the salt sensitivity of any given plant growth stage. Other studies show that beans react differently to salinity at different soil fertility levels. Although bean pod yield reductions due to salinity are greater in terms of yield per acre at high fertility, there is little relative difference. Highly significant interactions between salinity and fertility were obtained for vine weights, leaf/stem ratios, moisture content of plant tissue, and nitrogen, calcium and potassium content of the plant material.

At Prosser, Washington, sweet corn was matured one week earlier by planting under clear plastic. Soil temperatures were increased under the clear plastic and reduced under the black plastic as compared to plots without cover.

Plastic coatings on nitrogenous fertilizers show great potential for increasing the recovery of applied N in the Rio Grande Valley. At Weslaco, Texas, coated urea at the rate of 90 pounds of N per acre increased yields of sweet bell peppers by 12,880 pounds as compared to an increase of 690 pounds with a like amount of uncoated urea.

The greenhouse study on the compatibility of the growth retardant, tributyl-2,4-dichlorobenzyl-phosphonium chloride (Phosfon), with common fertilizer salts was continued through the first half of the year. Davidson soil used in the earlier experiment with tomatoes was

reseeded to pinto beans, in order to test for residual growth-regulating potency. Potency was found in year-old culture media that had been treated with 100 pounds of Phosfon per acre, though it was not noticeable with a 10-pound application.

At Prosser, Washington, sweet corn grown through clear plastic emerged earlier, developed more rapidly, and matured about one week earlier than corn grown on bare soil. Soil temperatures were increased by partial cover with clear plastic and reduced by partial cover with black plastic when compared to bare soil. Yields were depressed when the corn was grown through black plastic compared to bare soil.

At Raleigh, North Carolina, string beans and sweet corn demonstrated optimum yields at water table levels of 24 to 30 inches below the soil surface. Oxygen diffusion measurements permits one to determine the aeration status at various soil depths. It appears that where the water tables were maintained at a depth of 18 or more inches below the soil surface, the primary root zone was well aerated.

Subsoiling and deep placement of lime and fertilizer to stimulate deep root growth have not increased vegetable crop yields on a coastal plain soil in New Jersey.

PUBLICATIONS REPORTING RESULTS OF USDA AND COOPERATIVE RESEARCH

See areas 1 to 13.

Line Project Check List -- Reporting Year April 1, 1961 to March 31, 1962

Work & Line Project Number	Work and Line Project Titles	Work Locations During Past Year	Line Proj. Incl. in Summary of Progress	Line Proj. Incl. in Area & Sub-Subheading
SWC 1	Sedimentation processes in relation to watershed development and protection. Program leadership	Beltsville, Md.		
SWC 1-a1	Development and evaluation of means and measures for channel stabilization in the Northeast.	Beltsville, Md. Danville, Vt. East Aurora, N.Y. Cambridge, Mass. Oxford, Miss.	Yes	1-D
SWC 1-b1	Sediment production, yield and delivery ratio in relation to climatic factors and watershed characteristics in the Southern Branch and at the U.S. Sedimentation Laboratory.	Oxford, Miss. Cartersville, Ga.	Yes	1-A
SWC 1-b2	Investigations of the nature and processes of reservoir sedimentation in the Southern Branch and at the U.S. Sedimentation Laboratory.	Oxford, Miss.	Yes	1-B
SWC 1-b3	Mechanics of sediment entrainment, transportation and deposition in natural and artificial channels in the Southern Branch and at the U.S. Sedimentation Laboratory.	Oxford, Miss. Watkinsville, Ga. Ft. Lauderdale, Fla.	Yes	1-C
SWC 1-b4	Investigations of stream channel morphology in the Southern Branch and at the U.S. Sedimentation Laboratory.	Oxford, Miss. Watkinsville, Ga. Ft. Lauderdale, Fla. East Aurora, N.Y.	Yes	1-D
SWC 1-b5	Development of structural measures for sediment control and for stream channel stabilization in the Southern Branch and at the U.S. Sedimentation Laboratory.	Oxford Miss. East Aurora, N.Y.	No	
SWC 1-c1	Sediment sources, yields and deposition in agricultural watersheds in Corn Belt states.	Coshocton, Ohio	No	
SWC 1-c2	Stream channel stabilization, sediment control works in channels and mechanics of sediment entrainment, transportation and deposition therein, for Corn Belt states.	Madison, Wisc. Columbia, Mo. Coshocton, Ohio Oxford, Miss.	Yes	1-D
SWC 1-d1	Rates and processes of reservoir sedimentation and deposition of sediment in channels and valleys of the Northern Plains.	Lincoln, Nebr. Newell, S. Dak. Oxford, Miss.	Yes	1-B
SWC 1-d2	Sediment production, yield, and delivery ratio in relation to climatic, geologic, and watershed characteristics of the Northern Plains.	Lincoln, Nebr. Hastings, Nebr. Newell, S. Dak.	Yes	1-A
SWC 1-e1	Sediment production, movement, and deposition in agricultural watersheds in the Southern Great Plains.	Riesel, Tex. Chickasha, Okla. Stillwater, Okla. Oxford, Miss.	Yes	1-A
SWC 1-e2	Stream channel stabilization and sediment control works in channels in the Southern Great Plains.	Chickasha, Okla. Stillwater, Okla. Oxford, Miss.	Yes	1-D
SWC 1-f1	Sediment movement and deposition on upstream agricultural watersheds of the Pacific Northwest.	Boise, Idaho	No	
SWC 1-g1	Sediment yields of agricultural watersheds in the Southwest.	Tucson, Ariz. Santa Rosa, N. Mex. Riverside, Calif.	Yes	1-A
SWC 1-g2	Stream channel morphology and channel stability on agricultural watersheds in the Southwest.	Tucson, Ariz. Santa Rosa, N. Mex. Riverside, Calif. Oxford, Miss.	Yes	1-D
SWC 1-g3	Nature and processes of reservoir sedimentation in the Southwest.	Tucson, Ariz. Santa Rosa, N. Mex. Riverside, Calif.	No	

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Work & Line Project Number	Work and Line Project Titles	Work Locations During Past Year	Line Proj. Incl. in Summary of Progress	Line Proj. Incl. in Area & Sub-Subheading
SWC 2	Hydrology of agricultural watersheds and associated aquifers in relation to treatment for flood prevention and multiple use of water resources. Program Leadership	Beltsville, Md.		2-F,G
SWC 2-a1	The relation of rain, snow, and frozen soils to the hydrology of agricultural watersheds in the Northeast.	Danville, Vt. College Park, Md. Blacksburg, Va.	Yes	2-A
SWC 2-a2	Water yield in relation to climatic and watershed characteristics of land resource areas in the Northeast.	Danville, Vt. College Park, Md. Blacksburg, Va. Morgantown, W. Va.	Yes	2-E
SWC 2-a3	Storm runoff and flood flows in relation to climatic and watershed characteristics of land resource areas in the Northeast.	College Park, Md. Danville, Vt. Blacksburg, Va. Morgantown, W. Va.	Yes	2-F
SWC 2-aD1	Analytical hydrography in watershed engineering.	Beltsville, Md.	Yes	2-A,B,E,F,G
SWC 2-b1	Relation of climatic and watershed factors to runoff rates and volume yields in the Southern Branch.	Oxford, Mississippi Ft. Lauderdale, Fla.	Yes	2-B,E
SWC 2-b2	Precipitation characteristics influencing runoff from agricultural watersheds in the Southern Branch.	Oxford, Mississippi Ft. Lauderdale, Fla.	No	
SWC 2-b3	Runoff production by unit source area agricultural watersheds in the South.	Oxford, Mississippi	No	
SWC 2-b4	Subsurface and ground water accretion, depletion, movement and contribution to streamflow for agricultural watersheds in the Southern Branch.	Ft. Lauderdale, Fla. Oxford, Mississippi	Yes	2-C
SWC 2-c1	Precipitation and snow melt characteristics influencing runoff from agricultural watersheds in Corn Belt states.	Coshocton, Ohio Madison, Wisconsin	No	
SWC 2-c2	Runoff production by unit source area agricultural watersheds in Corn Belt states.	Coshocton, Ohio Madison, Wisconsin	No	
SWC 2-c3	Relation of climatic and watershed factors to storm runoff in Corn Belt states.	Coshocton, Ohio Madison, Wisconsin	Yes	2-F
SWC 2-c4	Relation of climatic and watershed physiographic and cultural factors to water yield in Corn Belt states.	Coshocton, Ohio Madison, Wisconsin	Yes	2-E
SWC 2-c5	Aquifer and subsurface relationships in the hydrology of upstream agricultural watersheds in Corn Belt states.	Coshocton, Ohio Madison, Wisconsin	Yes	2-B,D
SWC 2-d1	Water yield as related to integrated climatic and watershed characteristics in the Northern Plains.	Lincoln, Nebr. Hastings, Nebr. Newell, S. Dak.	Yes	2-D,E
SWC 2-d2	Storm runoff and floods as related to integrated climatic and watershed characteristics in the Northern Plains.	Hastings, Nebr. Newell, S. Dak.	Yes	2-F
SWC 2-e1	Precipitation characteristics influencing runoff from agricultural watersheds in the Southern Plains.	Chickasha, Okla. Riesel, Tex. Bushland, Tex.	Yes	2-A
SWC 2-e2	Runoff production by unit source areas in the Southern Plains.	Chickasha, Okla. Riesel, Tex.	No	
SWC 2-e3	Relation of climatic and watershed factors to storm runoff in the Southern Plains.	Riesel, Tex. Chickasha, Okla. Stillwater, Okla.	Yes	2-F
SWC 2-e4	Relation of climatic and watershed physiographic and cultural factors to water yield in the Southern Plains.	Riesel, Tex. Chickasha, Okla.	Yes	2-C,E
SWC 2-f1	Aquifer-streamflow interrelationships in upstream agricultural watersheds of the Pacific Northwest.	Boise, Idaho	Yes	2-C,D

Line Project Check List -- Reporting Year April 1, 1961 to March 31, 1962 (Continued)

Work & Line Project Number	Work and Line Project Titles	Work Locations During Past Year	Line Proj. Incl. in Summary of Progress	Line Proj. Incl. in Area & Sub-Subheading
SWC 2-f2	Precipitation characteristics influencing hydrologic performance of agricultural watersheds in the Pacific Northwest.	Boise, Idaho Moscow, Idaho	Yes	2-A
SWC 2-f3	Runoff and sediment movement on unit source watersheds of the Pacific Northwest as influenced by climate, soils, vegetation, and topography.	Boise, Idaho Moscow, Idaho	No	
SWC 2-f4	Water accumulation, flood-wave movement and water yield from complex watersheds of the Pacific Northwest.	Boise Idaho Moscow, Idaho	Yes	2-E,F
SWC 2-g1	Precipitation characteristics influencing the hydrology of agricultural watersheds in the Southwest.	Tucson, Ariz. Santa Rosa, N. Mex. Lompoc, Calif.	Yes	2-A
SWC 2-g2	Relation of integrated climatic, watershed, and cultural factors to storm runoff from agricultural watersheds in the Southwest.	Tucson, Ariz. Santa Rosa, N. Mex.	Yes	2-F
SWC 2-g3	Relation of integrated climatic, watershed, and cultural factors to water yields from agricultural watersheds in the Southwest.	Tucson, Ariz. Santa Rosa, N. Mex. Lompoc, Calif.	Yes	2-B,C,D,E

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Work & Line Project Number	Work and Line Project Titles	Work Locations During Past Year	Line Proj. Incl. in Summary of Progress	Line Proj. Incl. in Area & Sub-Subheading
SWC 3	Hydraulics of irrigation, drainage and watershed protection and water supply structures, channels, and facilities. Program Leadership	Beltsville, Md.		
SWC 3-c1	Hydraulic design of structures for water use and control in the Corn Belt.	Minneapolis, Minn. Coshocton, Ohio	Yes	3-A,B
SWC 3-e1	The hydraulics and measurement of channel, flood plain, and overland flow in the Southern Plains.	Stillwater, Okla. Chickasha, Okla.	Yes	3-A.C,D
SWC 3-e2	Hydraulic design of structures for water use and control in the Southern Plains.	Stillwater, Okla.	Yes	3-B
SWC 3-g1	The hydraulics of channel, flood plain, and overland flows in the Southwest.	Tucson, Ariz.	Yes	3-A

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Work & Line Project Number	Work and Line Project Titles	Work Locations During Past Year	Line Proj. Incl. in Summary of Progress	Line Proj. Incl. in Area & Sub-Subheading
SWC4	Conservation of water supplies for agricultural use. Program Leadership	Beltsville, Md.		
SWC4-b1	Development of water supplies for irrigation in the South	Tifton, Ga.	No	
SWC4-c1	Improvement of water supply sources and storage facilities in the Corn Belt	Columbia, Mo. McCredie, Mo.	Yes	4-A
SWC4-d1	Facilities, methods and design criteria for pumping, conveying, controlling and measuring irrigation water in the Northern Plains	Fort Collins, Colo.	Yes	4-B
SWC4-e1	Conservation and management of Playa Lake water for recharge and irrigation in the Southern Plains	Bushland, Tex.	No	
SWC4-g1	Control of water use by nonbeneficial plants and evaporation losses from storage and conveyance structures in the Southwest	Reno, Nev.	No	
SWC4-g2	Recharge facilities, methods, principles and design criteria for storing water in underground reservoirs in the Southwest	Fresno, Calif. Lompoc, Calif.	Yes	4-C
SWC4-g3	Control of agricultural water supply and conveyance seepage losses in the Southwest	Reno, Nev. Logan, Utah	Yes	4-A,B
SWC4-gG1	Measurement, evaluation and control of seepage losses	Tempe, Ariz.	Yes	4-A
SWC4-gG2	Atmospheric and related boundary mechanisms in water vapor losses from plant, soil and water surfaces	Tempe, Ariz.	Yes	4-A
SWC4-gG3	Measurement, evaluation and control of infiltration to conserve water	Tempe, Ariz.	Yes	4-B
SWC4-gG4	Physical processes in the soil affecting preventable losses of water by surface evaporation	Tempe, Ariz.	Yes	4-A
SWC4-gG5	Water measurement and control for water conservation	Tempe, Ariz.	Yes	4-B

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SWC 5	Irrigation principles, requirements, practices, and facilities for efficient use of water on farms. Program Leadership	Beltsville, Md.		
SWC 5-a1	Irrigation practices and factors affecting the water requirements of crops in different land resource areas of the Northeast.	New Brunswick, N.J. Blacksburg, Va.	Yes	5-A
SWC 5-b1	Irrigation requirements, practices and methods of application for efficient production of crops in the Southeast.	Watkinsville, Ga. Fort Lauderdale, Fla. Thorsby, Ala. Tifton, Ga. State College, Miss.	Yes	5-A
SWC 5-c1	Improvement in performance and design of irrigation systems in the Corn Belt.	Columbia, Mo.	Yes	5-B
SWC 5-d1	Irrigation practices, requirements and design criteria for efficient use of water and sustained crop production in the Northern Plains.	Fort Collins, Colo. Grand Junction, Colo. Mitchell, Nebr. Lincoln, Nebr. Laramie, Wyo. Newell, S. Dak.	Yes	5-A,C
SWC 5-e1	Irrigation water management for maximum use efficiency in growing crops in the Southern Plains.	Weslaco, Tex. Bushland, Tex.	Yes	5-C
SWC 5-f1	Irrigation requirements, principles, and practices for efficient use of water in the Pacific Northwest.	Prosser, Wash.	Yes	5-A
SWC 5-f2	Surface and sprinkler design and operation principles and facilities for efficient water use in the Pacific Northwest.	Boise, Ida.	Yes	5-B,C
SWC 5-g1	Basic irrigation principles in the Southwest.	Logan, Utah Reno, Nev. Brawley, Calif.	Yes	5-B
SWC 5-g2	Irrigation requirements of forage and cultivated crops in the Southwest.	Logan, Utah Reno, Nev. Lompoc, Calif. Los Angeles, Calif. Pomona, Calif.	Yes	5-C
SWC 5-g3	Intake, transmission and storage of water in irrigated lands in the Southwest.	Logan, Utah Reno, Nev. Davis, Calif. Pomona, Calif. Phoenix, Ariz.	Yes	5-A

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SWC 6	Drainage principles, requirements, practices, and facilities for protection of crops and soils. Program Leadership	Beltsville, Md.		
SWC 6-a1	Development and evaluation of surface and subsurface drainage practices in different land resource areas of the Northeast.	Ithaca, N. Y. Burlington, Vt. Blacksburg, Va.	Yes	6-C,E
SWC 6-b1	Drainage requirements of crops in the South.	Ft. Lauderdale, Fla. Raleigh, N.C.	Yes	6-E
SWC 6-b2	Design, installation, and maintenance of surface and subsurface drainage systems with or without land forming and conditioning in the South.	Ft. Lauderdale, Fla. Fleming, Ga. Baton Rouge, La.	Yes	6-E
SWC 6-c1	Improvement and modernization of surface and subsurface drainage practices and facilities in the Corn Belt.	Madison, Wisc. Morris and Minneapolis, Minn. Columbus, Ohio	Yes	6-A,B,E
SWC 6-d1	Drainage facilities, methods, and design criteria for protection and improvement of agricultural crops and soils in the Northern Plains.	Fort Collins, Colo. Grand Junction, Colo. Mandan, N. Dak.	Yes	6-E
SWC 6-e1	Basic drainage principles in the Southern Plains.	Weslaco, Tex.	Yes	6-D
SWC 6-e2	Surface and subsurface drainage systems, methods, materials, and evaluation in the Southern Plains.	Chickasha, Okla. Weslaco, Tex.	Yes	6-D
SWC 6-g1	Basic drainage principles in the Southwest.		No	
SWC 6-g2	Drainage facilities, methods and evaluation for irrigated lands in the Southwest.	Logan, Utah Reno, Nev. Pomona, Calif. Brawley, Calif.	Yes	6-B
SWC 6-g3	Drainage and aeration requirements of crops on irrigated lands in the Southwest.	Reno, Nev. Pomona, Calif.	Yes	6-D
SWC 6-gF1	Principles of drainage as related to salt-affected soils in the Southwest.	Riverside, Calif.	Yes	6-D

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SWC 7	Saline, sodic, and related soils problems, and quality of irrigation waters and their relation to plant growth processes. Program Leadership	Beltsville, Md.		
SWC 7-a1	Investigation of the effects of using saline and industrial waste waters on yield and quality of plants and on physical and chemical characteristics of soils in the Northeast.	Norfolk, Va. New Brunswick, N.J.	Yes	7-A, B
SWC 7-b1	The effect of brackish water on plants and soil.	Fleming, Ga.	No	
SWC 7-d1	Improvement and management of saline and sodic soils of the Northern Plains.	Grand Juction, Colo. Fort Collins, Colo. Mandan, N. Dak. Huntley, Mont.	Yes	7-E
SWC 7-e1	Saline and sodic soils and irrigation water quality problems in the Rio Grande River basin.	Weslaco, Tex.	Yes	7-B, C, D
SWC 7-f1	Soil and water management practices for the control or alleviation of saline and sodic soil problems in the Pacific Northwest	Ontario, Ore. Boise, Ida.	Yes	7-D
SWC 7-g1	Effect of leaching, amendments, water quality and soil and crop management practices on the soluble salt and adsorbed cation status of salt-affected Southwestern soils.	Pomona, Calif.	No	
SWC 7-gF1	Mechanisms of reactions between dissolved and adsorbed constituents of salt-affected soils.	Riverside, Calif.	Yes	7-A
SWC 7-gF2	Structure, organic matter, and microbial relation in salt-affected soils.	Riverside, Calif.	Yes	7-A
SWC 7-gF3	Methods for the diagnosis and study of salinity in soils and water.	Riverside, Calif.	Yes	7-A
SWC 7-gF4	Soil physical and chemical conditions in relation to plant growth on salt-affected soils.	Riverside, Calif.	Yes	7-A
SWC 7-gF5	Tolerance of economic plants to salinity and exchangeable sodium.	Riverside, Calif.	Yes	7-B
SWC 7-gF6	Plant-water relationships under saline, drought, or high exchangeable sodium conditions.	Riverside, Calif.	Yes	7-B
SWC 7-gF7	Effects of salinity and exchangeable-cation status on absorption, distribution, and metabolic effectiveness of ions in plants.	Riverside, Calif.	No	
SWC 7-gF8	Effects on plants of specific ions associated with salinity or exchangeable sodium.	Riverside, Calif.	Yes	7-B
SWC 7-gF9	Influence of climatic and edaphic factors on plant response to salinity and exchangeable sodium.	Riverside, Calif.	No	
SWC7-gF10	Chemical composition of irrigation waters in relation to their suitability for use.	Riverside, Calif.	Yes	7-C
SWC7-gF11	Principles of salinity control, including the amelioration of salt-affected soils by leaching and use of amendments.	Riverside, Calif.	No	

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SWC 8	Water and wind erosion control principles, practices, systems, and prediction methods for conservation of crop and rangeland Program Leadership	Beltsville, Md.		
SWC 8-a1	Determination and evaluation of factors affecting water runoff and erosion in the different land resource areas of the Northeast as related to soil and water conservation practices.	Blacksburg, Va. Orono, Me. Marcellus, N.Y. Durham, N.H.	Yes	8-A, B, D
SWC 8-b1	Effects of soil, topography, climate, cropping and management procedures on runoff and erosion, and on the prediction of soil losses in the South.	Watkinsville, Ga. Tifton, Ga. State College, Miss. Holly Springs, Miss.	Yes	8-B
SWC 8-b2	Development of supporting practices, systems, techniques and devices for runoff and erosion control in the South.	Watkinsville, Ga.	Yes	8-D
SWC 8-c1	Basic principles and mechanics of rainfall, runoff, soil movement and loss in the Corn Belt.	Morris, Minn. Ames, Iowa Lafayette, Ind. Urbana, Ill.	Yes	8-A
SWC 8-c2	Evaluation of climatic, topographic, soil and crop management factors in relation to water management and erosion control in the Corn Belt.	Morris, Minn. Ames, Iowa LaCrosse, Wisc. Columbia, Mo. Lafayette, Ind.	Yes	8-B
SWC 8-c3	Development and refinement of methods for predicting field runoff and soil loss.	Lafayette, Ind.	Yes	8-C
SWC 8-c4	Development of supporting runoff and erosion control practices and systems in the Corn Belt.	Ames, Iowa Morris, Minn. LaCrosse, Wisc. Columbia, Mo.	Yes	8-D
SWC 8-d1	Water erosion and its control on irrigated and non-irrigated lands in the Northern Plains.	Lincoln, Nebr. Akron, Colo.	Yes	8-B
SWC 8-e1	Wind erosion control in the Southern Plains.	Big Springs, Tex. Manhattan, Kan.	Yes	8-A,B,C,D
SWC 8-e2	Interrelations among soil-cover-practice complexes, precipitation, runoff, and erosion losses in the Southern Plains.	Cherokee, Okla. Temple, Tex. Bushland, Tex.	Yes	8-B
SWC 8-e3	Runoff water management for erosion control, moisture conservation, and leaching of saline soil areas.	Cherokee, Okla. Weslaco, Tex. Big Springs, Tex. Chickasha, Okla.	Yes	8-D
SWC 8-f1	Erosion and runoff control practices and systems to conserve soil and water resources in the Pacific Northwest.	Pullman, Wash. Pendleton, Ore. St. Anthony, Ida.	Yes	8-B
SWC 8-f2	Fundamental aspects of water erosion in the Pacific Northwest.		No	

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SWC 9	Moisture conservation for the efficient and effective use of precipitation on crop and range lands. Program Leadership	Beltsville, Md.		
SWC 9-c1	Development of soil management systems for efficient use of soil moisture in the Corn Belt Region.	Morris, Minn. Ames, Iowa La Crosse, Wis. Brookings, S. Dak.	Yes	9-A,B,C
SWC 9-d1	Improved water conservation and use on nonirrigated lands of the Northern Plains.	Akron, Colo. Fort Collins, Colo. Bozeman, Mont. Sidney, Mont. Lincoln, Nebr. North Platte, Nebr. Mandan, N. Dak. Newell, S. Dak. Laramie, Wyo.	Yes	9-A,B,C
SWC 9-e1	Conservation and efficient use of precipitation in the Southern Great Plains.	Manhattan, Kans. Woodward, Okla. Bushland, Tex. Temple-Riesel, Tex. Weslaco, Tex. Big Spring, Tex.	Yes	9-A,B,C
SWC 9-f1	Moisture conservation principles and practices in the Pacific Northwest.	Pendleton, Ore. St. Anthony, Idaho	Yes	9-A
SWC 9-g1	Perfecting cropping sequences, land and water management systems, and cultural practices to conserve and efficiently utilize precipitation.	Riverside, Calif.	Yes	9-B,C

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SWC 10	Soil properties, processes, and management in relation to the conservation and efficient use of land and water resources. Program Leadership	Beltsville, Md.		
SWC 10-a1	Development of improved soil management and conservation practices on croplands in different land resource areas of the Northeast.	Presque Isle, Maine Marcellus, N. Y. Marlboro, N. J. Blacksburg, Va.	Yes	10-A,C
SWC 10-a2	Development of improved soil management practices for grassland soils in different land resource areas of the Northeast.	State College, Pa.	Yes	10-C
SWC 10-aB1	Fixation of ammonium ion in soils and its release to plants.	Beltsville, Md.	No	
SWC 10-aB2	Biological transformations of nitrogen in soil, including biological interchange in the rhizosphere, non-symbiotic fixation, gaseous losses, and accumulation of toxic products.	Beltsville, Md. Thorsby, Ala.	Yes	10-A,D
SWC 10-aB3	Humus formation in soils and the interaction of organic compounds with clays.	Beltsville, Md.	Yes	10-D
SWC 10-aB4	Evaluation of soil-pesticide complexes, including their decomposition.	Beltsville, Md.	Yes	10-B
SWC 10-aB5	Biological fixation of atmospheric nitrogen by soil organisms.	Beltsville, Md. Ames, Iowa Blackville, S. C. Stoneville, Miss.	Yes	10-D
SWC 10-aB6	Genetic studies with nitrogen-fixing organisms.	Beltsville, Md.	Yes	10-D
SWC 10-aB7	The relationship between the soil as the source of nutrients and the ion uptake process in the plant.	Beltsville, Md.	Yes	10-A
SWC 10-aB8	Nutrient balance for plant growth as related to soil environment, plant species and variety, and the nature of added nutrient carriers.	Beltsville, Md.	Yes	10-A,B
SWC 10-aB9	Development of spectrochemical methods and foliar diagnostic procedures for soil and plant investigations.	Beltsville, Md.	No	
SWC 10-b1	The lime requirements of red and yellow podzolic and related soils.	Thorsby, Ala. Fleming, Ga. Tifton, Ga. Watkinsville, Ga. State College, Miss. Rio Piedras, P. R. Florence, S. C.	Yes	10-B
SWC 10-b2	The fertility requirement of exposed subsoils.	Cartersville, Ga. State College, Miss.	Yes	10-A
SWC 10-b3	Fertilization for efficient crop production under intensive management.	Thorsby, Ala. Fleming, Ga. Watkinsville, Ga. State College, Miss. Rio Piedras, P. R. Florence, S. C.	Yes	10-A
SWC 10-b4	Developing improved cropping systems for soil conservation.	Fleming, Ga. Watkinsville, Ga. Rio Piedras, P. R. Florence, S. C.	Yes	10-C
SWC 10-b5	Crop residue management and tillage practices for soil conservation and efficient production in the South.	Cartersville, Ga. Watkinsville, Ga. State College, Miss. Rio Piedras, P. R. Florence, S. C.	Yes	10-C
SWC 10-b6	Factors influencing crop rooting development and activity and means of increasing root development in the South.	Auburn, Ala. Baton Rouge, La.	Yes	10-B,C

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Work & Line Project Number	Work and Line Project Titles	Work Locations During Past Year	Line Proj. Incl. in Summary of Progress	Line Proj. Incl. in Area & Sub-Subheading
SWC 10-b7	Integration of improved practices for soil and water conservation in the South.	Fleming, Ga. Watkinsville, Ga. Rio Piedras, P. R.	Yes	10-C
SWC 10-c1	Moisture utilization in the Corn Belt as influenced by soil fertility level and management practices.	Ames, Iowa Morris, Minn. Brookings, S. Dak.	Yes	10-A
SWC 10-c2	Tillage practices and crop residue management for soil conservation and efficient production in the Corn Belt.	Ames, Iowa Morris, Minn. Columbia, Mo. La Crosse, Wis.	Yes	10-C
SWC 10-c3	Fundamental studies on the mechanism of soil structure formation in the Corn Belt.	St. Paul, Minn.	Yes	10-C
SWC 10-d1	Chemical reactions and availability of phosphates in Northern Plains soils as affected by fertilization, soil properties, and management.	Fort Collins, Colo. Grand Junction, Colo. Huntley, Mont. Mandan, N. Dak.	Yes	10-A
SWC 10-d2	Soil nitrogen transformations in relation to soil nitrogen maintenance and more efficient use of fertilizer nitrogen in the Northern Plains.	Fort Collins, Colo. Grand Junction, Colo. Huntley, Mont. Mandan, N. Dak. Newell, S. Dak.	Yes	10-A
SWC 10-d3	Fertilizer requirements and fertility status of Northern Plains soils for more efficient crop and forage production.	Fort Collins, Colo. Grand Junction, Colo. Huntley, Mont. Mandan, N. Dak. Laramie, Wyo.	Yes	10-A,C
SWC 10-d4	Improved soil management practices and systems for better conservation farming in the Northern Plains.	Bozeman, Mont. Mandan, N. Dak. Newell, S. Dak. North Platte, Nebr. Akron, Colo.	Yes	10-A
SWC 10-d5	Principles and practices of stubble-mulch maintenance for soil and water conservation in the Northern Plains.	Akron, Colo. Lincoln, Nebr. North Platte, Nebr. Mitchell, Nebr. Fort Collins, Colo. Sidney, Mont. Bozeman, Mont.	Yes	10-C
SWC 10-d6	Interrelationships of soil and climate as a basis for predicting applicability of research results, soil response to treatment, and crop yields under different levels of management in the Northern Plains.	Fort Collins, Colo. Akron, Colo.	Yes	10-C
SWC 10-e1	Interrelationships between soil structure and plant growth.	Woodward, Okla. Bushland, Tex. Big Spring, Tex.	Yes	10-A,C
SWC 10-e2	Nutritional requirements for cropland and rangeland in the Southern Great Plains.	Woodward, Okla. Bushland, Tex. Temple-Riesel, Tex. Weslaco, Tex. Big Spring, Tex. Univ. Park, N. Mex.	Yes	10-A,C
SWC 10-f1	Soil management practices for conservation farming in the Pacific Northwest.	Prosser, Wash. Pullman, Wash. St. Anthony, Idaho	Yes	10-A,B,C
SWC 10-f2	Chemistry and availability of nutrient elements in soils of the Pacific Northwest.	Prosser, Wash. Pendleton, Ore. Corvallis, Ore.	Yes	10-A,B
SWC 10-f3	Chemistry and effects of organic matter in soils of the Pacific Northwest.	Corvallis, Ore.	Yes	10-C
SWC 10-f4	Microbial equilibria in soils of the Pacific Northwest.	Prosser, Wash.	Yes	10-D

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SWC 10-g1	Principles of nutrient uptake and efficient fertilizer use in relation to moisture regime and irrigation practice, soil properties and crop nutrient requirements in the Southwest.	Brawley, Calif. Tucson, Ariz.	Yes	10-A
SWC 10-g2	Improvement of soil fertility, crop production and soil and water conservation through the use of fertilizers and soil amendments on rangeland and nonirrigated cropland in the Southwest.	Riverside, Calif.	Yes	10-A

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SWC 11	Soil, water, and plant relations as they affect use of land and water resources. Program Leadership	Beltsville, Md.		
SWC 11-a1	The energy budget at the earth's surface.	Ithaca, N. Y.	Yes	11-A,B
SWC 11-b1	Modification of soil surface structure and crop geometry to beneficially influence climatic conditions in the South.	Auburn, Ala. Thorsby, Ala.	Yes	11-A,C
SWC 11-b2	Plant factors influencing transpiration in the South.	Watkinsville, Ga. Florence, S. C.	Yes	11-B
SWC 11-b3	Gaseous losses of nitrogen under field conditions in the Southern States.	Thorsby, Ala.	Yes	10-A
SWC 11-b4	Reduction of strontium-90 by crops.	Watkinsville, Ga. Florence, S. C.	No	
SWC 11-c1	Soil moisture-plant growth relationships.	Urbana, Ill.	Yes	11-B,C
SWC 11-c2	Climatic influence on water use and crop performance in the Corn Belt Region.	Urbana, Ill. Morris, Minn. Crookston, Minn.	Yes	11-C
SWC 11-c3	Soil moisture flow problems and solutions in the Corn Belt Region.	Urbana, Ill. Columbus, Ohio	Yes	11-A
SWC 11-d1	Principles affecting soil structure stability and its effect on aeration intake, transmission and storage of water on irrigated lands in the Northern Plains.	Ft Collins, Colo.	Yes	11-A
SWC 11-e1	Understanding and improving soil-plant-atmospheric relationships for more efficient utilization of water.	Manhattan, Kans. Bushland, Tex. Weslaco, Tex. Univ. Park, N. Mex.	Yes	11-A,B
SWC 11-gF1	Physical properties and kinetics of change of the physical properties of water in soil-water systems.	Riverside, Calif. Logan, Utah	Yes	11-A
SWC 11-gG1	Uptake and disposal of water by plants in an arid climate.	Tempe, Ariz.	Yes	11-A,B,C

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SWC 12	Nutrition of animals as affected by properties and characteristics of soils and plants.	Ithaca, N. Y. & Other States		
SWC 12-aA1	Effects of soil and geological conditions on the composition of forages and other crops in relation to nutritional troubles in animals.	Ithaca, N. Y. Logan, Utah	Yes	12-A
SWC 12-aA2	Effect of environment, soil type and soil management on the nutritive quality of crops as measured by animal growth, health and reproduction.	Ithaca, N. Y.	Yes	12-A
SWC 12-aA3(c)	Micronutrient elements of soils and plants in relation to certain endemic nutritional diseases of animals.	Ithaca, N. Y. Reno, Nevada Corvallis, Ore.	Yes	12-B
SWC 12-aA4	The role of mineral elements, enzymes, nucleic acids and other factors in the biosynthesis of proteins.	Ithaca, N. Y.	Yes	12-C
SWC 12-aA5	Chemical reactions of micronutrient cations with clay minerals and plant extracts.	Ithaca, N. Y.	Yes	12-D
SWC 12-aA6	Toxicities in foods and forage plants with particular reference to nitrates and certain mineral elements.	Ithaca, N. Y. Athens, Ga.	Yes	12-A
SWC 12-aA7	Effect of plant nutrients on the amino acid and protein content of food and forage plants.	Ithaca, N. Y.	Yes	12-C
SWC 12-aA8	The role of mineral elements in the formation of the organic matrix of bone.	Ithaca, N. Y.	Yes	12-B

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SWC 13	Fertilizer investigations: Resources, production, and improvement. Program Leadership	Beltsville, Md.		
SWC 13-aC-1	Consumption of commercial fertilizers in the United States.	Beltsville, Md.	Yes	13-E
SWC 13-aC-2	Sources and trends in the production and use of fertilizers and plant nutrients.	Beltsville, Md.	Yes	13-E
SWC 13-aC3	Fertilizer resources and development in foreign countries.	Beltsville, Md.	Yes	13-E
SWC 13-aC-4	Development of sampling and analytical methods for fertilizers.	Beltsville, Md.	Yes	13-C
SWC 13-aC-5	Preparation of radioactive fertilizers.	Beltsville, Md.	Yes	13-B
SWC 13-aC-6	Effect of physical properties of nutrient materials on the granulation of fertilizer mixtures.	Beltsville, Md.	Yes	13-B
SWC 13-aC-7	Fertilizer as a vehicle for soil applications of growth regulators and herbicides.	Beltsville, Md.	Yes	13-D
SWC 13-aC-8	Suitability of nitrogen materials for fertilizer use.	Beltsville, Md.	Yes	13-A
SWC 13-aC-9	Separation of nitrogen components of fertilizers.	Beltsville, Md.	Yes	13-A
SWC 13-aC-10	Inhibitors of urea hydrolysis in soils.	Beltsville, Md.	Yes	13-A
SWC 13-aC-11	Physical characterization of phosphatic fertilizer materials.	Beltsville, Md.	Yes	13-A
SWC 13-aC-12	Nutritive value of water-insoluble phosphates in multinutrient fertilizers.	Beltsville, Md.	Yes	13-A
SWC 13-aC-13	Chemical composition and physical characteristics of agricultural limestone.	Beltsville, Md.	Yes	13-A
SWC 13-aC-14	Utilization of flue dust from cement kilns as a liming material and fertilizer.	Beltsville, Md.	Yes	13-A
SWC 13-aC-15	Development and evaluation of primary carriers of zinc for use in crop production.	Beltsville, Md.	Yes	13-A
SWC 13-aC-16	Amounts of nitrogen, phosphorus and potassium applied to economic crops in 1959.	Beltsville, Md.	Yes	13-E